NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

HAND-HELD COMPUTER PROGRAMS FOR
PRELIMINARY HELICOPTER DESIGN

by

Paul John Fardink

October 1982

Thesis Advisor: Donald M. Layton

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The first part consists of several short programs and their subroutine form. These programs and subroutines compute density

altitude, density, disc area, solidity, tip velocity, induced velocity, coefficient of thrust, tip loss factor, equivalent chord, and ground effect.

The second part consists of major subroutines. These subroutines compute profile power, induced power, climb power, parasite power, and total power; equivalent area and induced power for a tandem rotor; and data input and change.

The third part consists of the main programs. These programs compute the various power requirements for hovering flight, forward (straight and level) flight, vertical flight, and forward climbing flight; also tailrotor power, autorotative flight, and tandem rotor flight.

Hand-Held Computer Programs for Preliminary Helicopter Design

by

Paul John Fardink
Major, United States Army
B.S., United States Military Academy, 1970

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I. INTRODUCTION

A. BACKGROUND

This project was undertaken to give the user of the HP-41 Programmable Calculator a series of programs that would give acceptable results during the preliminary phases of the helicopter design process. The HP-41 is a handheld programmable calculator designed and manufactured by the Hewlett-Packard Company of Corvallis, Oregon. This personal computing system easily fits into a coat pocket, thus being able to go anywhere. This, in turn, gives the preliminary design engineer a computational versatility and flexibility not previously experienced. To date, no known project of this magnitude has been attempted with a handheld calculator.

B. GOALS

The single goal of this project was to construct a series of self-prompting, alpha-numeric programs that could be used with acceptable results during the preliminary helicopter design process. In doing this, this project supplements the theory and computational processes as outlined by Professor Donald M. Layton in Aircraft Performance [Ref. 1]. An additional projected end use was for utilization by the Aeronautical Engineering students of the Naval Postgraduate School enrolled in the Helicopter Performance and Helicopter Design courses.

II. APPROACH TO THE PROBLEM

The basic line of approach used in this project was to construct calculator programs consisting mainly of subroutines. The subroutine is the key ingredient of this effort for the following reasons:

1. The use of subroutines greatly reduces the amount of required calculator program memory. Numerous main programs utilize the same basic equations and computational techniques even though the end results will be different. When these processes are organized into subroutine format, the numerous main programs can call and execute these common subroutines repeatedly, until the desired outputs are calculated for the particular flight conditions. For example, program "FORFLT" and program "VERFLT" are different in that program "FORFLT" will calculate the power requirements for forward (straight and level) flight while program "VERFLT" will calculate the power requirements for vertical flight. The results will be different, yet both main programs will call and execute fifteen identical subroutines where computational techniques are the same for both programs. The end result being that program memory, i.e. the number of calculator registers required, is optimized.

2. The use of subroutines greatly enhances the ease of program editing. Each individual subroutine calculates a

single specific function or variable, i.e. rotor disc area, rotor solidity, ground effect, density of the air, etc. Perhaps the user of these programs does not agree with the theory used for calculating ground effect or perhaps the user knows of a shorter technique that will greatly reduce the required amount of program memory for storage of the subroutine. The user need only edit that particular subroutine and no more. Confusion has been minimized, and there is no need for massive amounts of program editing.

These subroutines and this project utilize the basic aerodynamic theories of the helicopter, and it is not the intention of this project to teach this theory, nor is it the intention of this project to teach calculator programming operations. The user of these programs is assumed to have a basic knowledge of helicopter aerodynamics and it is further assumed that the user is proficient with the HP-41 programmable calculator.

III. THE SOLUTION

A. PROGRAM AND SUBROUTINE ORGANIZATION

The program and subroutine documentation used throughout this project exists in six sections. The nature of each of these sections is as follows:

1. Purpose

This section gives a brief description of the intended purpose of the program or subroutine. This section will often show a listing of the various program displays and outputs.

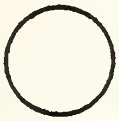
2. Equations

This section lists the various equations used within the program or subroutine. If the program or subroutine should call and execute another subroutine, this section will not list nor discuss the equations used by the "called" subroutine. This section will also list and describe the notation used in the equations listed. Whenever applicable, units are also listed as part of the notation description. The vast majority of the equations used in these programs come from Aircraft Performance [Ref. 1], NACA Report [1235] [Ref. 2], and Aerodynamics of V/STOL Flight [Ref. 3].

3. Flowchart

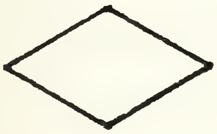
This section contains a flowchart which is an outline of the computational process utilized in the program or

subroutine. The standard HP-41 flowcharting symbols as outlined in the Hewlett-Packard Owner's Handbook and Programming Guide [Ref. 4] have been used:



circles for beginning and ending a program or subroutine

rectangles to represent the functional operations



diamonds to represent the decision processes.

The rectangle was modified somewhat from the standard HP notation in order to visually represent a subroutine:

modified rectangle to represent subroutine operation

4. Example Problems and User Instructions

This section represents a series of example problems that when executed by the user, will serve to familiarize the user with program operation, program displays, required calculator key strokes, program notation, program inputs, and program outputs. The example problems contain the design data of actual operational military helicopters which in turn serves to familiarize the user with these aircraft. A word of warning must be emphasized. The results or outputs

of these programs when compared with actual operational data are sometimes amazingly accurate, but at other times, they are not. Again, the theory used in computation uses numerous assumptions that do not take into account actual flight and operational conditions. Therefore, when executing power requirements, these programs should never be used in lieu of the appropriate manufacturer's performance charts or operator's manuals. Again, the purpose of these programs is to give the preliminary design engineer acceptable figures in the preliminary helicopter design process and not to supercede performance charts or operator's manuals.

5. Programs and Subroutines Used

This section lists all of the programs and subroutines used during the execution of the main program or subroutine. The user must insure that the listed programs and subroutines are in program memory before execution of the program is attempted otherwise the word "NONEXISTENT" will appear in the calculator display as the calculator searches for a subroutine or program that cannot be found in the calculator's program memory. As expected, the program cannot and obviously will not be executed.

6. Program Listings

This section contains a listing of the program lines of the program or subroutine. In some cases, as in Appendix B, both the program and its subroutine version are listed. The main programs listed in Appendix D will call and execute

many of the major subroutines listed in Appendix C as well as the minor subroutines listed in Appendix B.

IV. RESULTS

The results of this programming project are presented in Appendices B, C, and D. Appendix B contains many short programs and their subroutine form. These programs execute simple calculations such as solidity of the rotor system, rotor disc area, density of the air, etc. Appendix C contains major subroutines. These subroutines execute major calculations such as induced power, profile power, data input, tandem rotor equivalent area, etc. Appendix D contains the major programs for power required calculations. These main programs call and execute many of the minor subroutines found in Appendix B and many of the major subroutines found in Appendix C.

The validity of the output of these programs is excellent for the intended purpose of preliminary helicopter design calculations and estimations. As mentioned previously, the idealized theory used does make several assumptions and thus certain limitations are imposed upon the results. Some of the limitations are listed here:

1. Symmetric airfoils with zero twist are used throughout these programs. All actual helicopters have main rotor blades which utilize some degree of twist. This in turn will affect the overall lift generation and distribution.

2. The streamlining effects of the vertical fin on tail rotor power requirements in forward flight were not modeled and thus taken into account.

3. Compressibility effects on the advancing main rotor blade and stall effects on the retreating main rotor blade were not modeled and thus taken into account. Both of these effects will add to the overall horsepower requirements in forward flight computations.

4. The theory used did not take into account accessory losses such as hydraulic pumps, electrical generators, fuel pumps, heaters and air conditioners. Nor did the theory take into account drive train losses such as gear and transmission friction. All helicopter manufacturers will in some form incorporate these losses into their performance charts.

5. These programs do not take into account the main rotor downwash effects on the helicopter fuselage. This is a small horsepower requirement and was neglected here.

6. These programs do not take into account those real world operating conditions that have an overall effect on the performance of the helicopter. These conditions include, but are not limited to, engine erosion, dirty engine compressor blades, dirty and/or dented rotor blades. Again, these programs should not be substituted for performance charts and operator's manuals.

V. CONCLUSIONS AND RECOMMENDATIONS

The user of these programs should work through the example problems given in the various program and subroutine listings. In doing so, Table I, Appendix A, An Alphabetical Listing of All Calculator Displays and Their Intended Meaning, will become a valuable aid. Table II, Appendix A, Program and Subroutine Storage Requirements, will also become useful in that it readily assists the user in keeping track of the calculator memory required and remaining. And, if it becomes necessary, Table III, Appendix A, Storage Register Utilization, will assist the user in the program editing process in that it lists the program registers used and their contents; 32 program registers have been used. The user should insure that the calculator has been sized for Ø31 before attempting execution of the programs.

APPENDIX A

QUICK REFERENCE TABLES

The tables in this appendix will serve the user of this project as a source of quick reference. Table I is an alphabetical listing of all the possible calculator displays and their intended meanings. Table II lists all of the programs and subroutines and their respective storage requirements both in terms of registers required and bytes required. This table readily assists the user in keeping track of the calculator memory required and remaining. Table III lists the storage registers and their utilization. This table will assist the user in the program editing process.

TABLE I

AN ALPHABETICAL LISTING OF ALL CALCULATOR DISPLAYS AND THEIR INTENDED MEANINGS

Display	Explanation	Formula Notation
AREA=	Answer: rotor disc area in ft^2	A_D
a=?	Prompt: fraction of the radius where the taper starts on a tapered rotor blade (decimal value)	a
B=	Answer: tip loss factor (decimal value)	B
b=?	Prompt: number of blades in the rotor system	b
BOTH	indicates calculator is about to execute combination of vertical flight and horizontal flight (forward climbing flight)	-
C=?	Prompt: chord length of the rotor blade in ft	C
CdO=?	Prompt: average profile drag coefficient	$\bar{C}_{d_o}$
CE=	Answer: equivalent chord in ft	C_e
CHANGE?	Prompt: asks if the original input data now needs to be changed. 1 is Yes, 0 is No	-
C RV b R W	chord-rotational velocity-number of blades-radius-weight, press key on calculator keyboard directly beneath the variable in need of change	C Ω b R W
CT=	Answer: coefficient of thrust	C_T
C0=?	Prompt: root chord in ft	C_0

TABLE I
(continued)

Cl=?	Prompt: tip chord in ft	C_1
d=?	Prompt: distance between the rotor shafts of a tandem rotor helicopter in ft	d
DA=	Answer: density altitude in ft	h_ρ
DA=?	Prompt: density altitude in ft	h_ρ
d(HOR.GLIDE)=	Answer: horizontal distance travelled on the ground at the forward autorotative flight velocity for minimum rate of descent in ft	d
D.L.=	Answer: disc loading of the rotor system in lbs/ft^2	D.L.
D.N.=	Answer: density of the air $\frac{lb\text{-}sec^2}{ft^4}$ or $\frac{slug}{ft^3}$	ρ
F=	Answer: a non-dimensional coefficient used in autorotation calculations	$\bar{F}$
FOR ONLY?	Prompt: execute forward flight portion of program only? 1 is Yes, 0 is No	-
FOR V=?	Prompt: forward flight velocity in kts	V_f
F.P.A.(FF)=?	Prompt: equivalent flat plate area for forward flight calculations in ft^2	f_f
F.P.A.(VF)=?	Prompt: equivalent flat plate area for vertical flight calculations in ft^2	f_v
GE=0	Answer: ground effect on the induced power is equal to zero	-

TABLE I
(continued)

GE=0,RATIO=1	Answer: ground effect on the induced power is equal to zero, therefore the ground effect ratio is equal to 1	-
H=?	Prompt: height of the rotor system above the ground in ft	h
HOVER?	Prompt: execute hovering flight portion of program only? 1 is Yes, 0 is No	-
LCM=?	Prompt: lift coefficient multiplier in drag coefficient terms	K_1
L(TAIL)=?	Prompt: tail length; distance from center of main rotor shaft to center of tailrotor shaft in ft	ℓ_t
M(TIP)=	Answer: Mach Number at the tip of the advancing rotor blade	M_T
PA=?	Prompt: pressure altitude in ft	h_p
PC=	Answer: climb power in horsepower	P_c
PI=	Answer: induced power in horsepower	P_i
PI(TL)=	Answer: induced power with tip losses in horsepower	$P_{i(TL)}$
PI(TL+GE)=	Answer: induced power with tip losses plus ground effect in horsepower	$P_{i(TL+GE)}$
PO=	Answer: profile power in horsepower	P_o
PO(TDM)=	Answer: profile power for a tandem rotor helicopter in horsepower	P_o

TABLE I
(continued)

PP=	Answer: parasite power in horsepower	P_p
PT(ACFT)=	Answer: total power for the aircraft in horsepower	P_T
PT(MR)=	Answer: total power for the main rotor in horsepower	P_T
PT(TDM)=	Answer: total power for a tandem rotor helicopter in horsepower	P_T
PT(TR)=	Answer: total power for the tailrotor in horsepower	P_T
R=?	Prompt: radius of the rotor system in ft	R
RATIO=	Answer: ground effect ratio	-
REC=?	Prompt: is the rotor blade of rectangular planform? 1 is Yes, 0 is No	-
RV=?	Prompt: rotational velocity of the rotor system in radians/second	Ω
SOLID=	Answer: the solidity of the rotor system	σ_r
T=?	Prompt: ambient temperature in degrees celsius	T(°C)
TR DATA	the calculator is now ready to prompt for the tailrotor data input	-
U=	Answer: the advance ratio	μ
VERT ONLY?	Prompt: execute vertical flight portion of program only? 1 is Yes, 0 is No	-
VERT V=?	Prompt: vertical velocity in ft/min	V_v

TABLE I
(continued)

VF(MIN.R.O.D.)=	Answer: forward autorotative flight velocity for minimum autorotative rate of descent in kts	V_f
VI=	Answer: induced velocity in ft/sec	V_i
VT=	Answer: velocity at the rotor tip in ft/sec	V_T
VV=	Answer: vertical autorotative velocity in a vertical autorotation in ft/min	V_v
VV(MIN.R.O.D.)=	Answer: vertical autorotative velocity (ft/min) at the forward autorotative flight velocity for minimum autorotative rate of descent	V_v
W=?	Prompt: weight of the helicopter in lbs	W

TABLE II

PROGRAM AND SUBROUTINE
STORAGE REQUIREMENTS

	Subroutine			Program		
Subject Area	Name	Reg	Byte	Name	Reg	Byte
Appendix B:						
Density Altitude	-	-	-	"DA"	12	84
Density	"DN"	7	48	"DENSITY"	4	27
Disc Area	"AD"	2	14	"AREA"	4	32
Solidity	"SD"	3	18	"SOLID"	6	46
Tip Velocity	"VT"	2	13	"VTIP"	6	37
Induced Velocity	"VI"	3	19	"VIND"	6	44
Coefficient of Thrust	"CT"	3	18	"CTHRUST"	8	58
Tip Loss Factor	"TL"	3	19	"TIPLOSS"	10	67
Equivalent Chord	-	-	-	"ECHORD"	10	70
Ground Effect	"GE"	8	59	"GEFFECT"	10	71
Appendix C						
Coefficients	"CF"	7	54	-	-	-
Vertical Component of Induced Velocity	"VC"	24	168	-	-	-
Data Input	"DATA	11	81	-	-	-
Change of Data	"CG"	17	121	-	-	-

TABLE II (continued)

Subject Area	Name	Reg	Byte	Name	Reg	Byte
Profile Power	"PO"	9	62	-	-	-
Induced Power	"PI"	16	112	-	-	-
Climb Power	"PC"	5	31	-	-	-
Parasite Power	"PP"	6	41	-	-	-
Total Power	"PT"	5	34	-	-	-
Equivalent Area Tandem Rotor	"AE"	7	47	-	-	-
Induced Power Tandem Rotor	"PIT"	15	108	-	-	-
Appendix D						
Hover	-	-	-	"HOVER"	10	66
Forward Flight	-	-	-	"FORFLT"	19	140
Vertical Flight	-	-	-	"VERFLT"	19	133
All Flight Regimes	-	-	-	"FLIGHT"	30	205
Tailrotor	-	-	-	"TR"	40	281
Autorotation	-	-	-	"AUTO"	32	221
Tandem Rotor	-	-	-	"TANDEM"	24	168
Checks	-	-	-	"CHECKS"	14	96

TABLE III

STORAGE REGISTER UTILIZATION

Storage Register	Stored Quantity
00	blank - used for computations
01	C_0 - the root chord of the rotor blade (ft)
02	C_1 - the tip chord of the rotor blade (ft)
03	a - fraction of radius where the taper starts on a tapered rotor blade (decimal value)
04	C or C_e - the chord or equivalent chord length of the rotor blade (ft)
05	R - the radius of the rotor system (ft)
06	b - the number of blades in the rotor system
07	$\bar{C}_{d_o}$ - the average profile drag coefficient
08	Ω - the rotational velocity of the rotor system (radians/sec)
09	h - rotor system height above the ground (ft)
10	W - weight of the helicopter (lbs)
11	ρ - density of the air $\frac{\text{lb-sec}^2}{\text{ft}^4}$ or $\frac{\text{slug}}{\text{ft}^3}$
12	A_D - rotor disc area (ft^2)
13	V_T - velocity of the rotor tip (ft/sec)
14	C_T - coefficient of thrust
15	B - tip loss factor
16	$P_{i(TL)}$ - induced power with tip losses (horsepower)
17	h/D - height ÷ diameter of rotor system used for ground effect calculations

TABLE III
(continued)

18	$P_{i(TL+GE)}$ - induced power with tip losses plus ground effect (horsepower)
19	σ_r - the solidity of the rotor system
20	v_i - induced velocity (ft/sec)
21	P_o - profile power (horsepower)
22	blank - used for computations
23	V_v - vertical velocity (ft/sec)
24	f_v - equivalent flat plate area for vertical flight calculations (ft^2)
25	V_f - forward velocity (ft/sec)
26	f_f - equivalent flat plate area for forward flight calculations (ft^2)
27	v_{i_T} - vertical component of the induced velocity through the rotor system for forward climbing flight (ft/sec)
28	P_p - parasite power (horsepower)
29	P_c - climb power (horsepower)
30	P_T - total power (horsepower)
31	indirect storage register - used by all the main programs in conjunction with Subroutine "CG"

note - Subroutine "CF", Subroutine "VC", and Program "TR" contain the only deviations from the above table in storage register utilization. This is done to optimize calculator storage requirements. The appropriate program or subroutine listing gives a complete explanation for the appropriate deviation. The calculator should be sized for 032.

APPENDIX B

MINOR PROGRAMS AND SUBROUTINES

This appendix consists of several short programs and their subroutine form. These programs compute density altitude, density, disc area, solidity, tip velocity, induced velocity, coefficient of thrust, tip loss factor, equivalent chord, and ground effect. The subroutines will be called and executed by the main programs in appendix D.

DENSITY ALTITUDE

1. PURPOSE

This program computes the density altitude, h_ρ, in feet when given the pressure altitude, h_p, in feet and the temperature in degrees celsius. The equation used for this program is based upon the standard atmosphere and described in NACA Report (1955) No. 1235 [Ref. 2]. This equation and thus this program is accurate to an altitude of 36,089 feet (isothermal level).

2. EQUATIONS

$$\frac{(1 - K_1 h_p)^{5.2561}}{(1 - K_1 h_\rho)^{4.2561}} = \frac{T}{T_{ssl}} \qquad (1)$$

where:

T is the ambient temperature (absolute)

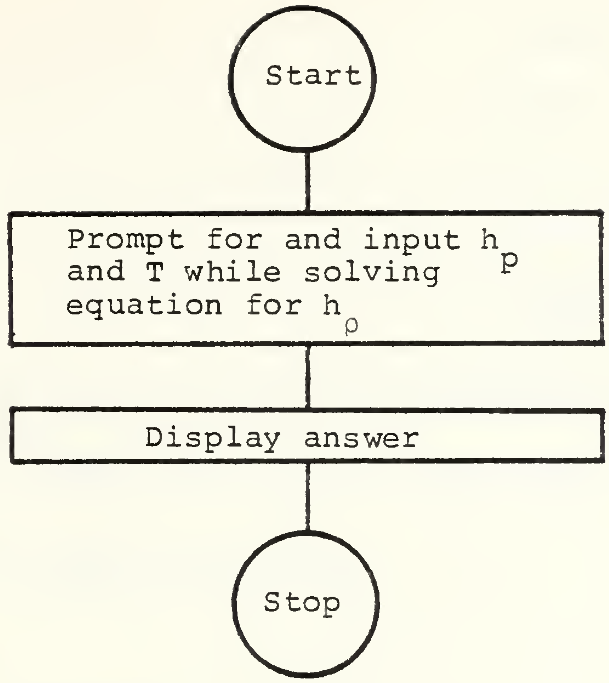
T_{ssl} is the standard sealevel temperature (absolute)

h_p is the pressure altitude (feet)

h_ρ is the density altitude (feet)

K_1 is a constant equal to 6.875×10^{-6}

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

The altimeter of a UH-60A currently indicates a pressure altitude of 1600 feet and the O.A.T. (Outside Air Temperature) gauge indicates 24° Celsius. What is the density altitude?

Keystrokes:	Display:
[XEQ] [ALPHA] DA [ALPHA]	PA=?
1600 [R/S]	T=?
24 [R/S]	DA=3,006.48

note - do not touch the calculator and proceed immediately to the next problem

The same UH-60A is now sitting On the deck of a ship. The altimeter indicates 0 feet and the O.A.T. gauge indicates 15°.

What is the density altitude?

Keystrokes:	Display:
[R/S] [R/S]	PA=?
0 [R/S]	T=?
15 [R/S]	DA=0.00
	(standard day sea level conditions)

note - pushing the run stop [R/S] button twice will reposition the calculator to the top of the program

5. PROGRAMS & SUBROUTINES USED

"DA"

6. PROGRAM LISTINGS

```
01♦LBL "DA"
02 "PA=?"
03 PROMPT
04 6.875 E-
06
05 *
06 CHS
07 1
08 +
09 5.2561
10 Y↑X
11 "T=?"
12 PROMPT
13 273.16
14 +
15 /
16 288.16
17 *
18 .23496
19 Y↑X
20 CHS
21 1
22 +
23 6.875 E-
06
24 /
25 FIX 2
26 "DA="
27 ARCL X
28 AVIEW
29 END
```

DENSITY

1. PURPOSE

This program/subroutine computes the density of the air at a given altitude. The equation used for this calculation is based upon the standard atmosphere and described in NACA Report No. 1235 [Ref. 2]. This equation and thus this program is accurate to an altitude of 36,089 feet (isothermal level). This program is therefore considered sufficient for all computations using density, ρ, here and in succeeding programs.

2. EQUATIONS

$$\rho = \rho_{ssl}\left[1 - (K_1)(h)\right]^{4.2561} \tag{2}$$

where:

ρ_{ssl} is the density of the air at standard sea level conditions which is equal to $0.0023769 \left[\frac{lb \cdot sec^2}{ft^4}\right]$ or $\left[\frac{slug}{ft^3}\right]$

K_1 is a constant equal to 6.875×10^{-6}

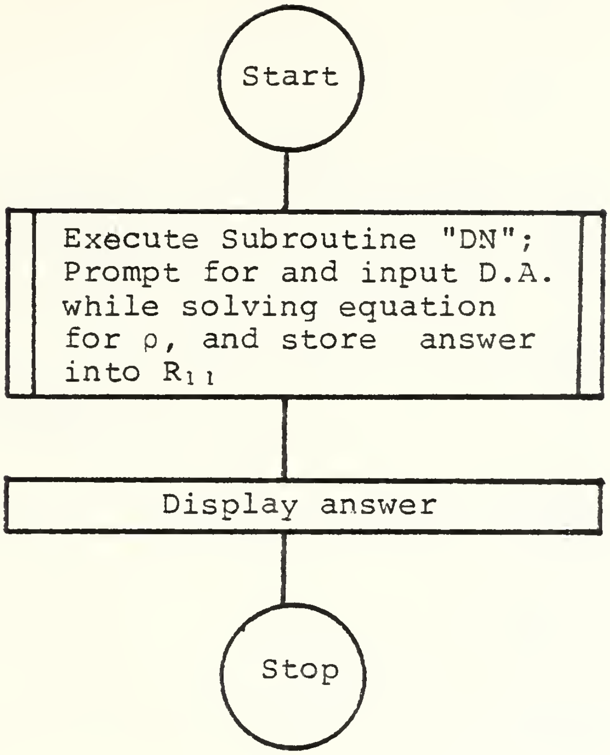
h is the density altitude (ft)

ρ is the density of the air at level h

with the input of known values, the equation to be programmed now becomes:

$$\rho = 0.0023769\left[1 - (6.875 \times 10^{-6})(h)\right]^{4.2561} \tag{3}$$

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the density, ρ, at a density altitude, D.A., of 1000 feet.

Keystrokes:	Display:
[XEQ] [ALPHA] DENSITY [ALPHA]	D.A.=?
1000 [R/S]	DN=0.0023081

note - do not touch the calculator and proceed immediately to the next problem

Find the density, ρ, at a density altitude, D.A., of 5283 feet.

Keystrokes:	Display:
[R/S] [R/S]	D.A.=?
5,283 [R/S]	DN=0.0020306

note - pushing the run stop [R/S] button twice will reposition the calculator to the top of the program

Find the density, ρ, at a density altitude, D.A., of 0 feet (sea level).

Keystrokes:	Display:
[R/S] [R/S]	D.A.=?
0 [R/S]	DN=0.0023769 (standard day sea level conditions)

5. PROGRAMS & SUBROUTINES USED

"DENSITY"
"DN"

6. PROGRAM LISTINGS

PROGRAM

```
01♦LBL "DEN
SITY"
02 XEQ "DN"
03 FIX 7
04 "DN="
05 ARCL X
06 AVIEW
07 END
```

SUBROUTINE

```
01♦LBL "DN"
02 "D.A.=?"
03 PROMPT
04 6.875 E-
06
05 *
06 CHS
07 1
08 +
09 ENTER↑
10 4.2561
11 Y↑X
12 .0023769
13 *
14 STO 11
15 END
```

DISC AREA

1. PURPOSE

This program/subroutine calculates the disc area of a rotor system when given the radius. The disc area is the total area enscribed by the plane of the rotor without coning.

2. EQUATIONS

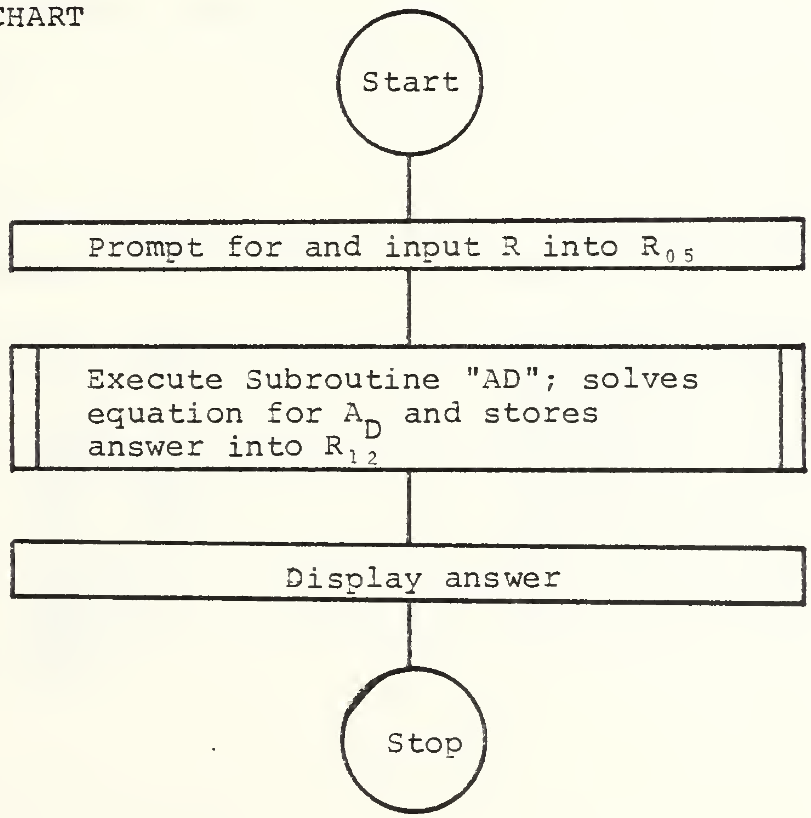
$$A_D = \pi R^2 \qquad (4)$$

where:

A_D is the Disc Area (ft^2)

R is the rotor system radius (ft)

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

The rotor radius of the UH-60A Blackhawk is 26.83 feet. Find the Disc Area.

Keystrokes:	Display:
[XEQ] [ALPHA] AREA [ALPHA]	R=?
26.83 [R/S]	AREA=2,261.47

The rotor radius of the AH-1T SeaCobra is 24.00 feet. Find the Disc Area.

Keystrokes:	Display:
[R/S] [R/S]	R=?
24.00 [R/S]	AREA=1,809.56

5. PROGRAMS AND SUBROUTINES USED

"AREA"
"AD"

6. PROGRAM LISTINGS

PROGRAM

```
 01♦LBL  "ARE
A"
 02  "R=?"
 03  PROMPT
 04  STO 05
 05  XEQ "AD"
 06  FIX 2
 07  "AREA="
 08  ARCL X
 09  AVIEW
 10  END
```

SUBROUTINE

```
 01♦LBL  "AD"
 02  RCL 05
 03  X↑2
 04  PI
 05  *
 06  STO 12
 07  END
```

SOLIDITY

1. PURPOSE

This program/subroutine computes solidity, σ_r, the fraction of the disc area that is composed of blades, i.e. solid.

2. EQUATIONS

$$\sigma_r = \frac{b\ c\ R}{\pi\ R^2} = \frac{b\ c}{\pi\ R} \tag{5}$$

where:

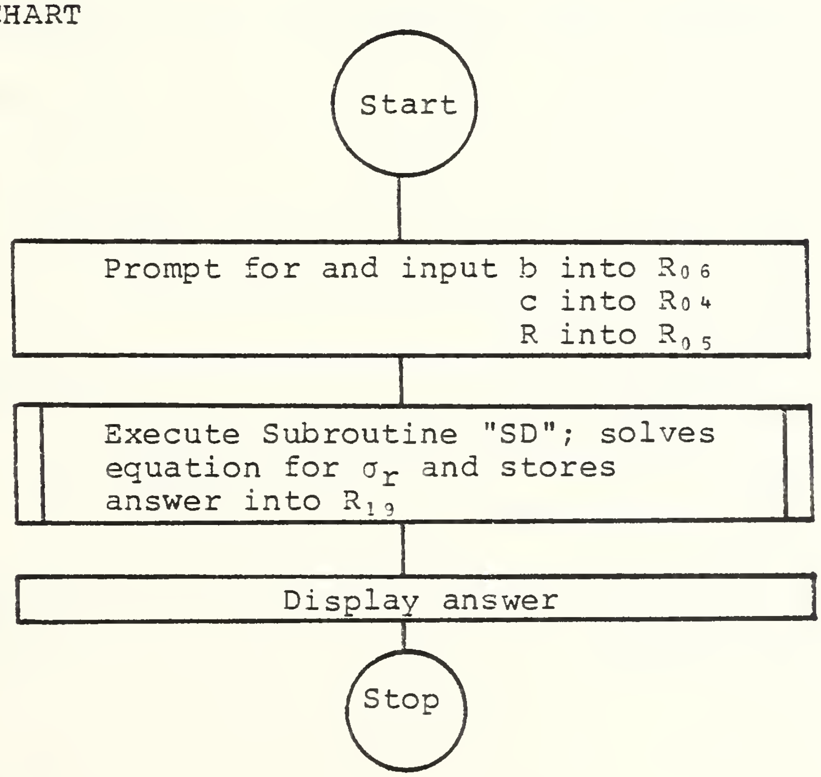
σ_r is the solidity of the rotor system

b is the number of rotor blades in the rotor system

R is the radius of the rotor system (ft)

c is the chord length of the rotor blade (ft)

3. FLOWCHART



4. SAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the solidity, σ_r, of the aft rotor system on the CH-46E Sea Knight (note - the fore and aft rotor systems both have the same dimensions).

$R = 25.50$ ft

$c = 1.5625$ ft

$b = 3$

Keystrokes:	Display:
[XEQ] [ALPHA] SOLID [ALPHA]	b=?
3 [R/S]	C=?
1.5625 [R/S]	R=?
25.50 [R/S]	SOLID=0.05851

Find the solidity, σ_r, of the main rotor system of the CH-54A Skycrane.

$R = 36.00$ ft

$c = 1.972$ ft

$b = 6$

Keystrokes:	Display:
[R/S]	b=?
6 [R/S]	C=?
1.972 [R/S]	R=?
36.00 [R/S]	SOLID=0.10462

5. PROGRAMS & SUBROUTINES USED

"SOLID"
"SD"

6. PROGRAM LISTINGS

PROGRAM

```
 01♦LBL "SOL
ID"
 02 "b=?"
 03 PROMPT
 04 STO 06
 05 "C=?"
 06 PROMPT
 07 STO 04
 08 "R=?"
 09 PROMPT
 10 STO 05
 11 XEQ "SD"
 12 FIX 5
 13 "SOLID="
 14 ARCL X
 15 AVIEW
 16 END
```

SUBROUTINE

```
 01♦LBL "SD"
 02 RCL 06
 03 RCL 04
 04 *
 05 RCL 05
 06 /
 07 PI
 08 /
 09 STO 19
 10 END
```

TIP VELOCITY

1. PURPOSE

This program/subroutine computes the tip velocity of the rotor blade. The tip velocity, V_T, is the product of the rotational velocity, Ω, and the rotor radius, R.

2. EQUATIONS

$$V_T = \Omega R \tag{6}$$

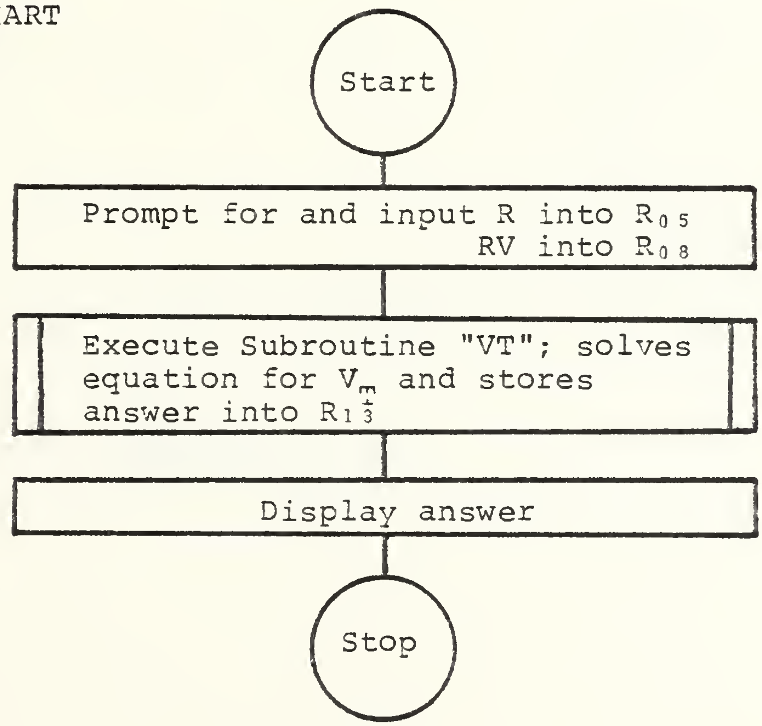
where:

V_T is the velocity of the rotor tip (ft/sec)

Ω is the rotational velocity (radians/sec)

R is the rotor radius (ft)

3. FLOWCHART



4. SAMPLE PROBLEMS AND USER INSTRUCTIONS

The rotor radius of a CH-53D Sea Stallion is 36.11 feet and the normal rotational velocity is 19.37 radians/sec. Find the tip velocity.

Keystrokes:	Display:
[XEQ] [ALPHA] VTIP [ALPHA]	R=?
36.11 [R/S]	RV=?
19.37 [R/S]	VT=699.45

The rotor radius of an AH-64 is 24.00 feet and the normal rotational velocity is 30.26 radians/sec. Find the tip velocity.

Keystrokes:	Display:
[R/S]	R=?
24 [R/S]	RV=?
30.26 [R/S]	VT=726.24

note - to convert RPM to radians/sec, divide by 9.55

5. PROGRAMS & SUBROUTINES USED

"VTIP"
"VT"

6. PROGRAM LISTINGS

PROGRAM

```
01◆LBL "VTI
P"
02 "R=?"
03 PROMPT
04 STO 05
05 "RV=?"
06 PROMPT
07 STO 08
08 XEQ "VT"
09 FIX 2
10 "VT="
11 ARCL X
12 AVIEW
13 END
```

SUBROUTINE

```
01◆LBL "VT"
02 RCL 08
03 RCL 05
04 *
05 STO 13
06 END
```

INDUCED VELOCITY

1. PURPOSE

This program/subroutine computes the induced velocity, v_i, the total inflow velocity through the rotor system during hover.

2. EQUATIONS

$$v_i = \left[\frac{T}{2\rho \cdot A_D} \right]^{1/2} \tag{7}$$

where:

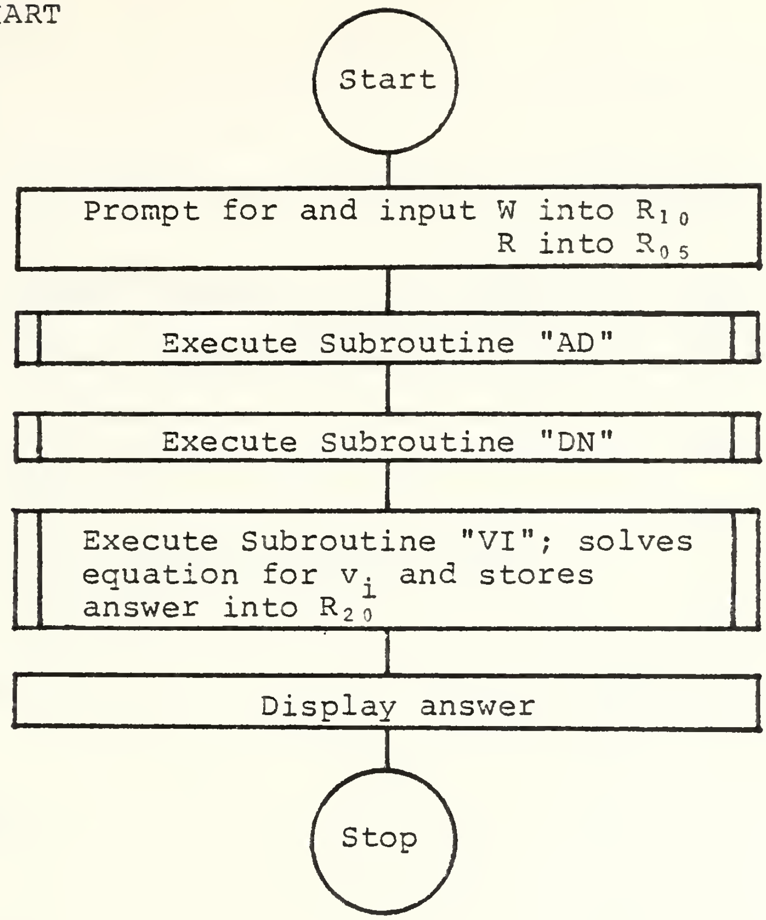
v_i is the induced velocity (ft/sec)

ρ is the density of the air $\left[\frac{\text{lb} \cdot \text{sec}^2}{\text{ft}^4} \right]$

A_D is the rotor disc area (ft^2)

T is the thrust which is equal to the weight, W (lbs)

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the induced velocity, v_i, of the main rotor system of a hovering SH-2F LAMPS under the following conditions:

DA = 0 (sea level)

W = 11,300 lb

R = 22.0 ft

note - insure that Subroutines "AD" and "DN" are in program memory

Keystrokes:	Display:
[XEQ] [ALPHA] VIND [ALPHA]	W=?

11,300 [R/S]	R=?
22.0 [R/S]	D.A.=?
0 [R/S]	VI=39.54

Find the induced velocity, v_i, of the main rotor system of a hovering CH-54A Skycrane under the following conditions:

D.A. = 2000 ft

R = 36 ft

W = 42,500 (maximum gross weight)

Keystrokes:	Display:
[R/S]	W=?
42,500 [R/S]	R=?
36 [R/S]	D.A.=?
2,000 [R/S]	VI=48.26

5. PROGRAMS & SUBROUTINES USED

"VIND"
"VI"
"AD"
"DN"

6. PROGRAM LISTINGS

PROGRAM

```
 01♦LBL "VIN
D"
 02 "W=?"
 03 PROMPT
 04 STO 10
 05 "R=?"
 06 PROMPT
 07 STO 05
 08 XEQ "AD"
 09 XEQ "DN"
 10 XEQ "VI"
 11 FIX 2
 12 "VI="
 13 ARCL X
 14 AVIEW
 15 END
```

SUBROUTINE

```
 01♦LBL "VI"
 02 RCL 10
 03 2
 04 /
 05 RCL 11
 06 /
 07 RCL 12
 08 /
 09 SQRT
 10 STO 20
 11 END
```

COEFFICIENT OF THRUST

1. PURPOSE

This program/subroutine computes the coefficient of thrust for a given rotor system. The coefficient of thrust is a non-dimensional coefficient established to facilitate computations and comparisons. [Ref.1]

2. EQUATIONS

$$C_T = \frac{T}{A_D \cdot \rho \cdot V_T^{\,2}} \qquad (8)$$

where:

C_T is the coefficient of thrust (non-dimensional)

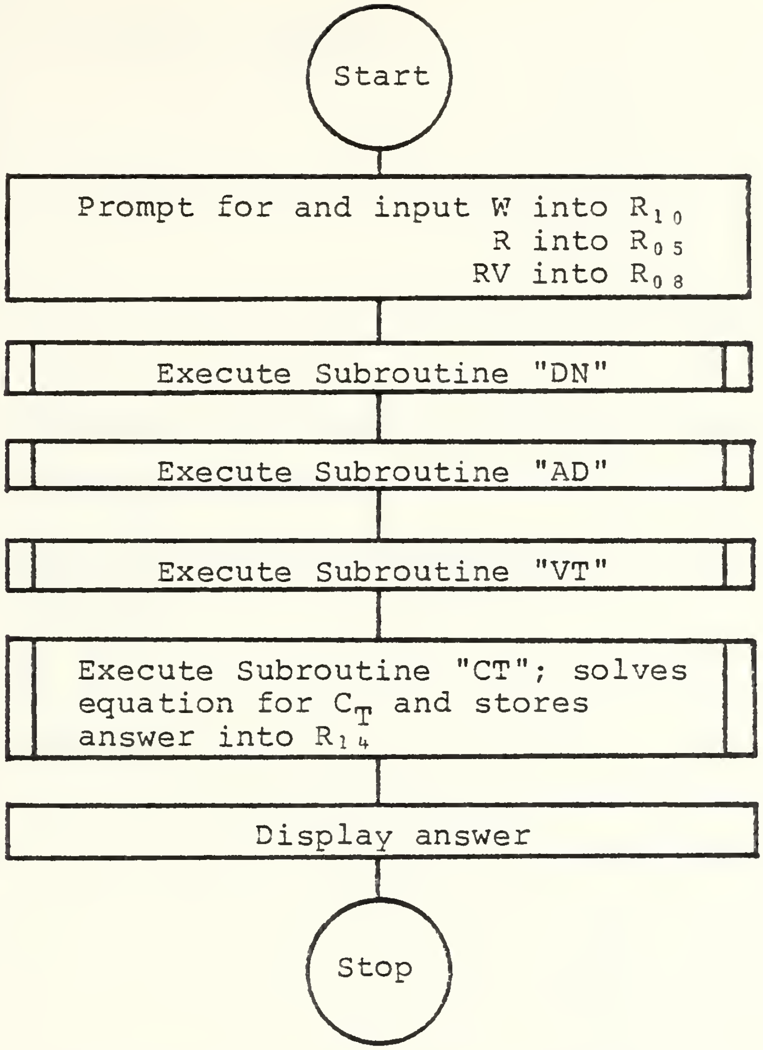
A_D is the disc area (ft^2)

V_T is the tip velocity (ft/sec)

ρ is the density of the air $\left[\frac{lb \cdot sec^2}{ft^4}\right]$

T is the thrust which is equal to the weight, W (lb)

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the coefficient of thrust, C_T, for a UH-1H Iroquois operating under the following conditions:

$N = 305$ RPM $\rightarrow \Omega = 31.94$ radians/sec

D.A. = 1600 ft

W = 8400 lbs

R = 24.09 ft

Keystrokes:	Display:
[XEQ] [ALPHA] CTHRUST [ALPHA]	W=?
8,400 [R/S]	R=?
24.09 [R/S]	RV=?
31.94 [R/S]	D.A.=?
1,600 [R/S]	CT=0.0034320

Find the coefficient of thrust, C_T, for an OH-6A operating under the following conditions:

$N = 470$ RPM $\rightarrow \Omega = 49.21$ radians/sec

D.A. = 4000 ft

W = 2500 lb

R = 13.165 ft

Keystrokes:	Display:
[R/S]	W=?
2,500	R=?
13.165	RV=?
49.21	D.A.=?
4,000	CT=0.0051824

5. PROGRAMS & SUBROUTINES USED

"CTHRUST"
"CT"
"DN"
"AD"
"VT"

6. PROGRAM LISTINGS

PROGRAM

```
01♦LBL "CTH
RUST"
02 "W=?"
03 PROMPT
04 STO 10
05 "R=?"
06 PROMPT
07 STO 05
08 "RV=?"
09 PROMPT
10 STO 08
11 XEQ "DN"
12 XEQ "AD"
13 XEQ "VT"
14 XEQ "CT"
15 FIX 7
16 "CT="
17 ARCL X
18 AVIEW
19 END
```

SUBROUTINE

```
01♦LBL "CT"
02 RCL 10
03 RCL 11
04 /
05 RCL 12
06 /
07 RCL 13
08 X↑2
09 /
10 STO 14
11 END
```

TIP LOSS FACTOR

1. PURPOSE

This program/subroutine computes the tip loss factor, B. Tip vortices, at the tip of the rotor blades, tend to despoil the pressure difference at the tips and thereby reduces the lift at the tips. The extent of these losses depends upon the rotor blade loadings, and number of blades. Numerous theories exist. The theory used in this subroutine is an approximation of the tip loss factor made by Prandtl and Betz. [Ref. 1] After the tip loss factor, B, has been computed in the subroutine and returned to the main programs used later, the induced power will change in accordance with the following equation:

$$P_{i_{TL}} = \frac{P_i}{B} \tag{9}$$

where:

$P_{i_{TL}}$ is the induced power with tip losses

P_i is the induced power

B is the tip loss factor

2. EQUATIONS

$$B = 1 - \frac{\sqrt{2C_T}}{b} \tag{10}$$

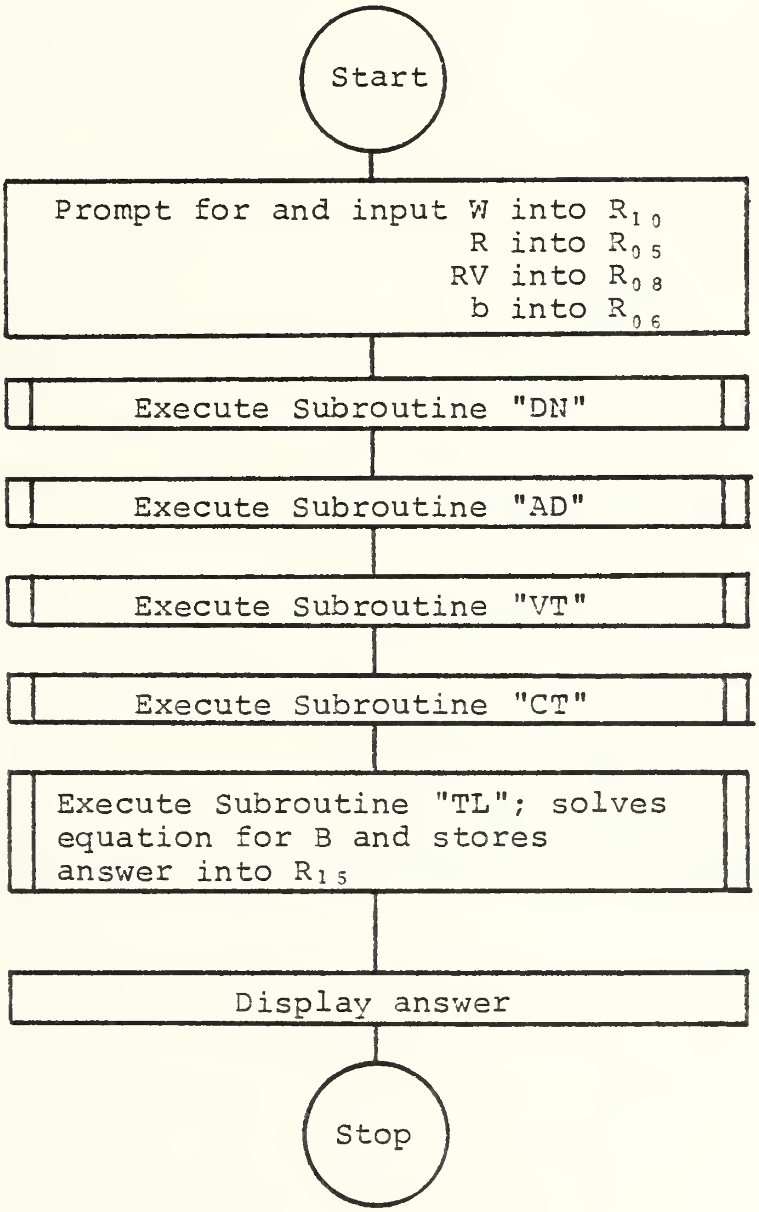
where:

C_T is the coefficient of thrust

b is the number of rotor blades

B is the tip loss factor

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the tip loss factor, B, for an OH-6A Cayuse operating under the following conditions:

$N = 470$ RPM $\rightarrow \Omega = 49.21$ radians/sec

D.A. = 5,000 ft

W = 2,150 lbs

R = 13.165 ft

b = 4

Keystrokes:	Display:
[XEQ] [ALPHA] TIPLOSS [ALPHA]	W=?
2150 [R/S]	R=?
13.165 [R/S]	RV=?
49.21 [R/S]	b=?
4 [R/S]	D.A.=?
5000 [R/S]	B=0.9760

Find the tip loss factor, B, for the same helicopter in the above problem, only this time use the maximum gross weight of W = 2550 lbs.

Keystrokes:	Display:
[R/S]	W=?
2550 [R/S]	R=?
13.165 [R/S]	RV=?

49.21 [R/S]	b=?
4 [R/S]	D.A.=?
5000 [R/S]	B=0.9739

5. PROGRAMS & SUBROUTINES USED

"TIPLOSS"
"TL"
"DN"
"AD"
"VT"
"CT"

6. PROGRAM LISTINGS

PROGRAM

```
01♦LBL "TIP
LOSS"
02 "W=?"
03 PROMPT
04 STO 10
05 "R=?"
06 PROMPT
07 STO 05
08 "RV=?"
09 PROMPT
10 STO [illegible]
11 [illegible]=?"
12 PROMPT
13 STO 06
14 XEQ "DN"
15 XEQ "AD"
16 XEQ "VT"
17 XEQ "CT"
18 XEQ "TL"
19 FIX 4
20 "B="
21 ARCL X
22 AVIEW
23 END
```

SUBROUTINE

```
01♦LBL "TL"
02 RCL 14
03 2
04 *
05 SQRT
06 RCL 06
07 /
08 CHS
09 1
10 +
11 STO 15
12 END
```

EQUIVALENT CHORD

1. PURPOSE

This program is also used as a subroutine by the main programs. This program computes the equivalent chord, C_e, for a tapered rotor blade. A tapered rotor blade (the chord at the tip less than the chord at the root) has less tip loss effect due to the smaller surface area over which the losses may occur; this is the primary reason for tapering the tips of the rotor blades. [Ref. 1]

2. EQUATIONS

The calculation for equivalent chord for thrust determinations has reduced to the following figure and equation:

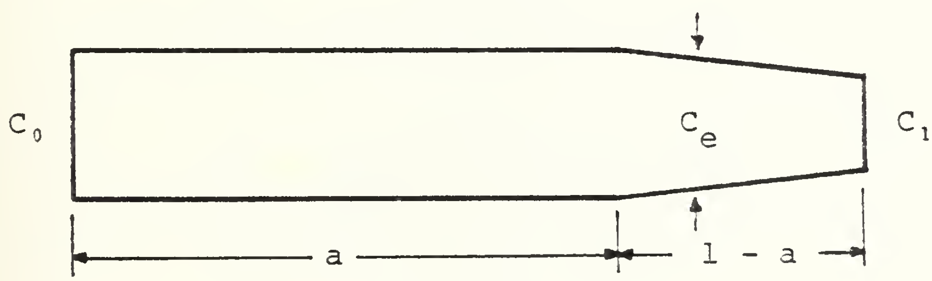


FIGURE 1
Tapered Rotor Blade

$$C_e = C_1 + \frac{1}{4}\left[\frac{C_0 - C_1}{1 - a}(1 - a^4)\right] \qquad (11)$$

where:

C_e is the equivalent chord (ft)

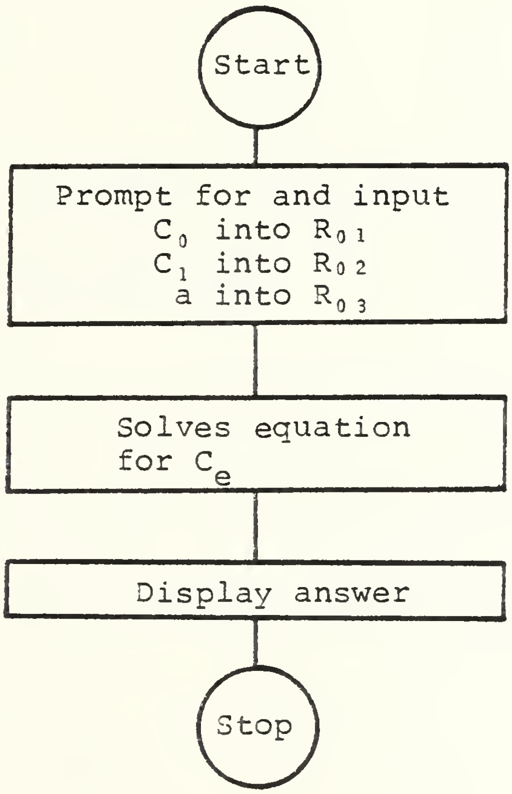
C_0 is the root chord (ft)

C_1 is the tip chord (ft)

a is the fraction of radius where the taper starts (decimal value)

note - when a = 0, the blade has a linear taper from the root to the tip. When a = 1, the blade is completely rectangular, and $C_e = C$

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the equivalent chord, C_e, for a tapered rotor blade with the following dimensions:

$C_0 = 1.6$ ft

$C_1 = 0.8$ ft

$a = .75$

Keystrokes:	Display:
[XEQ] [ALPHA] ECHORD [ALPHA]	C0=?
1.6 [R/S]	C1=?
0.8 [R/S]	a=?
.75 [R/S]	CE=1.347

Find the equivalent chord, C_e, for a tapered rotor blade with the following dimensions:

$C_0 = 1.0$ ft

$C_1 = 0.9$ ft

$a = .9$

Keystrokes:	Display:
[R/S] [R/S]	C0=?
1 [R/S]	C1=?
.9 [R/S]	a=?
.9 [R/S]	CE=0.986

5. PROGRAMS & SUBROUTINES USED

"ECHORD"

6. PROGRAM LISTINGS

PROGRAM

```
 01♦LBL "ECH
ORD"
 02 "C0=?"
 03 PROMPT
 04 STO 01
 05 "C1=?"
 06 PROMPT
 07 STO 02
 08 "a=?"
 09 PROMPT
 10 STO 03
 11♦LBL "EC"
 12 RCL 03
 13 ENTER↑
 14 4
 15 Y↑X
 16 CHS
 17 1
 18 +
 19 RCL 01
 20 ENTER↑
 21 RCL 02
 22 -
 23 *
 24 RCL 03
 25 CHS
 26 1
 27 +
 28 /
 29 4
 30 /
 31 RCL 02
 32 +
 33 FIX 3
 34 "CE="
 35 ARCL X
 36 AVIEW
 37 STOP
 38 END
```

1. PURPOSE

This program/subroutine computes the ground effect ratio P/P_{OGE}, as a function of the ratio of the rotor system height above the ground to the diameter of the rotor system. [Ref. 1] FIGURE 2 is a graph which shows the ratio of power required to hover in-ground-effect to that required to hover out-of-ground-effect for the average helicopter. This curve was obtained as the best fit to considerable amounts of test data on both single and tandem rotor helicopters. [Ref. 3]

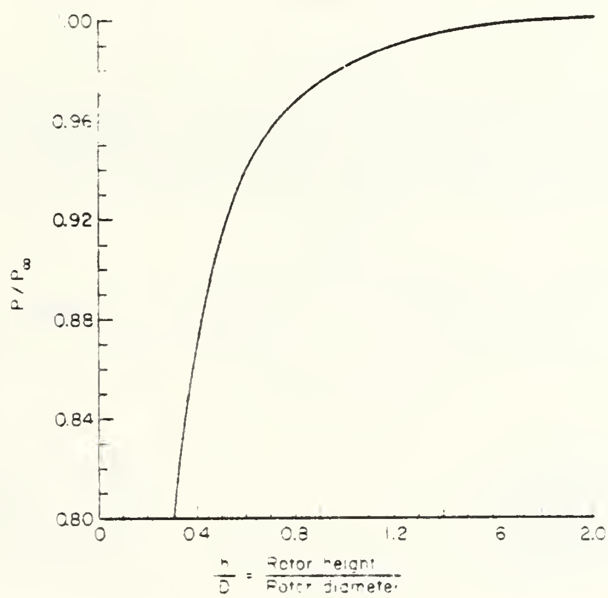


FIGURE 2
Ground Effect Curve [Ref. 3]

2. EQUATIONS

A curve fitting equation for the plot of FIGURE 2 results in the following equation:

$$\text{G.E. RATIO} = \frac{P}{P_{OGE}} = \left[-0.1276(h/D)^4 + 0.7080(h/D)^3 - 1.4569(h/D)^2 + 1.3432(h/D) + 0.5147 \right] \quad (12)$$

where:

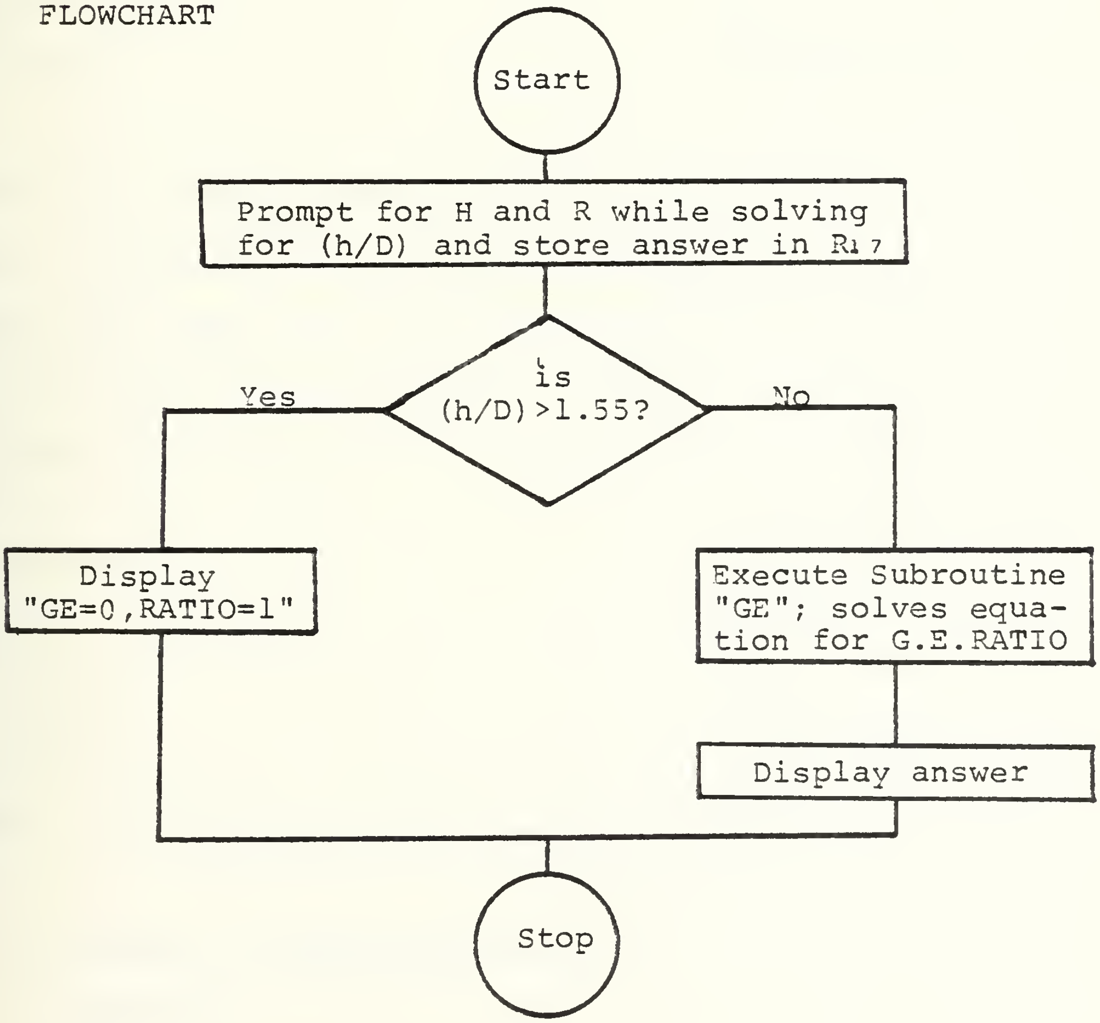
h is the height of the rotor system above the ground (ft)

D is the diameter of the rotor system (ft)

P is the power in-ground-effect

P_{OGE} is the power out-of-ground effect

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

The rotor radius of an SH-3H is 31.0 ft. It is currently hovering above the deck of the antisubmarine carrier Yorktown with the rotor system 24.33 ft above the deck (wheels 10 ft above the deck). What is the ground effect ratio?

Keystrokes:	Display:
[XEQ] [ALPHA] GEFFECT [ALPHA]	H=?
24.33 [R/S]	R=?
31 [R/S]	RATIO=0.8572

The rotor radius of an AH-1S Cobra is 22.0 ft. It is moving into a holding position behind and just below the top of some tall cover with the rotor system 70.0 ft above the ground (skids 58.0 ft above the ground). What is the ground effect ratio?

Keystrokes:	Display:
[R/S]	H=?
70 [R/S]	R=?
22 [R/S]	GE=0,RATIO=1

note - the Cobra is hovering out of ground effect

5. PROGRAMS & SUBROUTINES USED

"GEFFECT"
"GE"

6. PROGRAM LISTINGS

PROGRAM

```
 01♦LBL "GEF
FECT"
 02 "H=?"
 03 PROMPT
 04 "R=?"
 05 PROMPT
 06 2
 07 *
 08 /
 09 STO 17
 10 1.55
 11 -
 12 X>0?
 13 GTO 01
 14 XEQ "GE"
 15 FIX 4
 16 "RATIO="
 17 ARCL X
 18 AVIEW
 19 GTO 02
 20♦LBL 01
 21 "GE=0,RA
TIO=1"
 22 PROMPT
 23♦LBL 02
 24 END
```

SUBROUTINE

```
01♦LBL "GE"
02 RCL 17
03 1.3432
04 *
05 RCL 17
06 X↑2
07 -1.4569
08 *
09 +
10 RCL 17
11 3
12 Y↑X
13 .7080
14 *
15 +
16 RCL 17
17 4
18 Y↑X
19 -.1276
20 *
21 +
22 .5147
23 +
24 END
```

APPENDIX C

MAJOR SUBROUTINES

This appendix consists of several major subroutines that are called and executed by the main programs of appendix D. These subroutines compute the vertical component of the induced velocity for forward climbing flight; prompt for data input; prompt for change of original data input; compute profile power, induced power, climb power, parasite power, and total power all for a single rotor helicopter; and compute the equivalent area and the induced power requirements for a tandem rotor helicopter.

COEFFICIENTS

1. PURPOSE

This is a Subroutine used by those main programs that deal with forward climbing flight computations. This Subroutine calculates and stores the coefficients of a fourth order equation which Subroutine "VC" will recall and use to solve for the one real root of this equation. This real root is the vertical component of the induced velocity, v_{i_T}, which when multiplied with the thrust, T, gives the product of induced power, P_i, for forward climbing flight.

2. EQUATIONS

$$A(v_{i_T})^4 + B(v_{i_T})^3 + C(v_{i_T})^2 + D(v_{i_T}) + E = 0 \qquad (13)$$

where:

$A = 1.0$

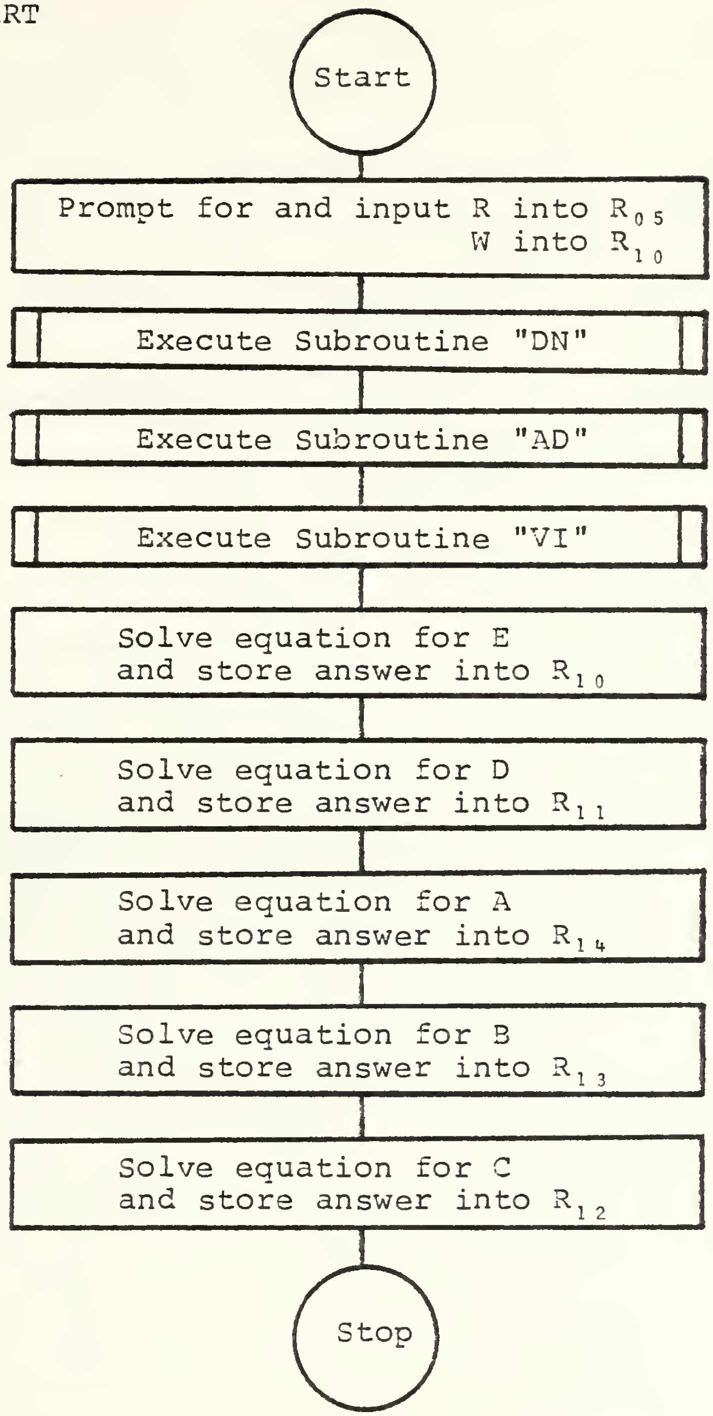
$B = 2V_v$ — V_v is the vertical velocity (ft/sec)

$C = (V_f^2 + V_v^2)$ — V_f is the forward velocity (ft/sec)

$D = 0$ — v_i is the induced velocity at a hover (ft/sec)

$E = -v_i^4$

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

This subroutine is immediately followed by Subroutine "VC" when used in the main programs. During its computation, Subroutine "VC" uses storage registers R_{00} through R_{19}.

It is therefore necessary to use Subroutine "DATA" at a latter time in the main program in order to get the input data properly stored into the correct memory registers. Because of this, some repetition of input data prompting will occur during main program usage.

5. PROGRAMS AND SUBROUTINES USED

"CF"
"DN"
"AD"
"VI"

6. PROGRAM LISTINGS

SUBROUTINE

```
♦LBL "CF"
"R=?"
PROMPT
STO 05
"W=?"
PROMPT
STO 10
XEQ "DN"
XEQ "AD"
XEQ "VI"
4
Y↑X
CHS
STO 10
0
STO 11
1
STO 14
RCL 23
2
*
STO 13
2
/
X↑2
RCL 25
X↑2
+
STO 12
END
```

VERTICAL COMPONENT OF INDUCED VELOCITY

1. PURPOSE

Subroutine "VC" is a subroutine used by those main programs that deal with forward climbing flight computations. It will immediately follow Subroutine "CF" in the main program listing because Subroutine "VC" recalls the coefficients of a fourth equation that Subroutine "CF" previously calculated. Subroutine "VC" uses the input of these coefficients to solve for the one real root of this fourth order equation. This real root is v_{i_T}, the vertical component of the induced velocity through the rotor system for forward climbing flight computations. Subroutine "VC" is a shortened version of Program "MHL". Program "MHL" was obtained from the Catalog of Contributed Programs HP-41C User's Library. [Ref. 5] When given a polynomial with real coefficients, Program "MHL" will use Maehly's Method, a modification of the well-known Newton's Method to find the real roots of the equation. In its original form, Program "MHL" has 131 program steps. This program was modified for use as Subroutine "VC" with 105 program steps.

2. EQUATIONS

See Subroutine "CF" for a complete description of the fourth order equation that Subroutine "VC" solves.

Neither the equations used in the iterative root solving process are shown, ncr is a flowchart for this process shown.

A complete description of this process is available from the HP-41C User's Library Catalog, Program Number 00660C. [Ref. 5]

3. FLOWCHART

none

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

The user may wonder why Subroutine "CF" and Subroutine "VC" were not combined into one subroutine. Subroutine "VC" has previously appeared in several different forms. Each form has solved the fourth order polynomial using a different technique. Subroutine "VC" currently exists in the shortest form found; both in number of program steps and program running time. Perhaps the user of this subroutine is aware of an even shorter process and can thus modify this subroutine even farther. It is important to remember here that one of the primary reasons for the use of subroutines was for ease of program editing and modification.

5. PROGRAMS & SUBROUTINES USED

"VC"

6. PROGRAM LISTINGS

SUBROUTINE

```
01♦LBL "VC"
02 FIX 2
03 SF 00
04 SF 01
05 CF 29
06 4
07 STO 00
08 10.01
09 +
10 STO 06
11 STO 08
12 RCL 00
13 .1
14 %
```

```
15 RCL Z
16 +
17 STO 07
18 CLX
19 STO 01
20 20
21 STO 02
22 FC?C 01
23 GTO 02
24 1 E-3
25 STO 04
26♦LBL 02
27 RCL 02
28 XEQ "AB"
29 X=0?
30 GTO 05
31 RCL 02
32 XEQ "BA"
33 STO 05
34 FS? 00
35 GTO 04
36 RCL 07
37 STO 09
38♦LBL 03
39 RCL 03
40 RCL 02
41 RCL IND
09
42 -
43 /
44 ST- 05
45 DSE 09
46 GTO 03
47♦LBL 04
48 RCL 02
49 RCL 03
50 RCL 05
51 /
52 -
53 ENTER↑
54 X<> 02
55 -
56 RCL 02
57 /
58 ABS
59 RCL 04
60 X<Y?
61 GTO 02
62♦LBL 05
63 CF 00
64 1
65 ST+ 01
66 ST+ 07
67 RCL 02
68 STO 27
69 GTO 08
70♦LBL "AB"
71 RCL 06
72 STO 08
73 RDN
74 RCL X
75 0
76♦LBL 06
77 RCL IND
08
78 +
79 *
80 DSE 08
81 GTO 06
82 RCL 10
83 +
84 STO 03
85 RTN
86♦LBL "BA"
87 RCL 06
88 STO 08
89 RDN
90 RCL X
91 RCL X
92 0
93♦LBL 07
94 *
95 RCL 08
96 INT
97 10
98 -
99 RCL IND
08
100 *
101 +
102 DSE 08
103 GTO 07
104♦LBL 08
105 END
```

DATA

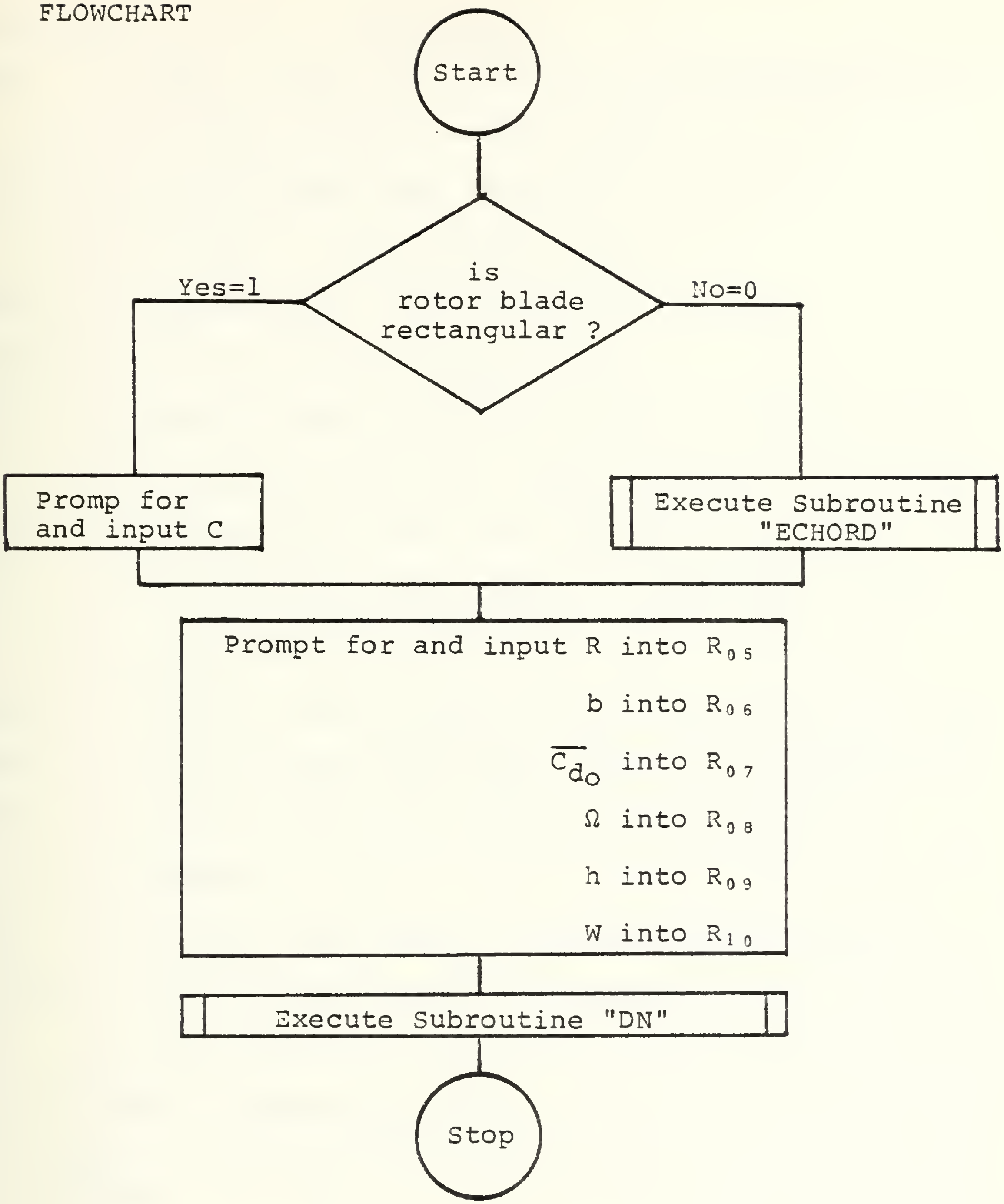
1. PURPOSE

This is a subroutine used by all main programs for data input, and depending upon the looping involved, some programs will use this subroutine more than once. In some very few instances, not every item of data that the calculator prompts for is required for program execution. In these few instances, the EXAMPLE PROBLEMS AND USER INSTRUCTIONS sections are very explicit in the correct procedures to be taken for data input. The primary reason in the repetitive use of this subroutine is to save program steps and calculator memory. Alpha characters and operators, the main ingredient of this subroutine, are more costly in storage requirements (bytes) than the typical numerical operators that are used throughout these programs. [Ref. 4]

2. EQUATIONS

none

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

No equations are used, but this subroutine prompts for the following input where:

Display:	Explanation:
REC?	asks if the rotor blade is of rectangular planform
	1 [R/S] if the answer is yes
C=?	asks for the blade chord (ft)
	0 [R/S] if the answer is no
C0=?	asks for the root chord (ft)
C1=?	asks for the tip chord (ft)
a=?	asks for the fraction of radius of the rectangular portion of the blade (decimal value)
R=?	asks for the rotor disc radius (ft)
b=?	asks for the total number of individual blades in the rotor system
Cd0=?	asks for the average profile drag coefficient, $\bar{C}_{d_o}$
RV=?	asks for the rotational velocity, Ω (radians/sec)
H=?	asks for the rotor system height above the ground, h (ft)
W=?	asks for the weight of the helicopter (lbs)
D.A.=?	asks for the density altitude, h_ρ (ft)

5. PROGRAMS & SUBROUTINES USED

"DATA"
"ECHORD"
"DN"

6. PROGRAM LISTINGS

SUBROUTINE

```
 01♦LBL "DAT
A"
 02 "REC?"
 03 PROMPT
 04 X>0?
 05 GTO 10
 06 XEQ "ECH
ORD"
 07 GTO 11
 08♦LBL 10
 09 "C=?"
 10 PROMPT
 11♦LBL 11
 12 STO 04
 13 "R=?"
 14 PROMPT
 15 STO 05
 16 "b=?"
 17 PROMPT
 18 STO 06
 19 "CdO=?"
 20 PROMPT
 21 STO 07
 22 "RV=?"
 23 PROMPT
 24 STO 08
 25 "H=?"
 26 PROMPT
 27 STO 09
 28 "W=?"
 29 PROMPT
 30 STO 10
 31 XEQ "DN"
 32 END
```

CHANGE

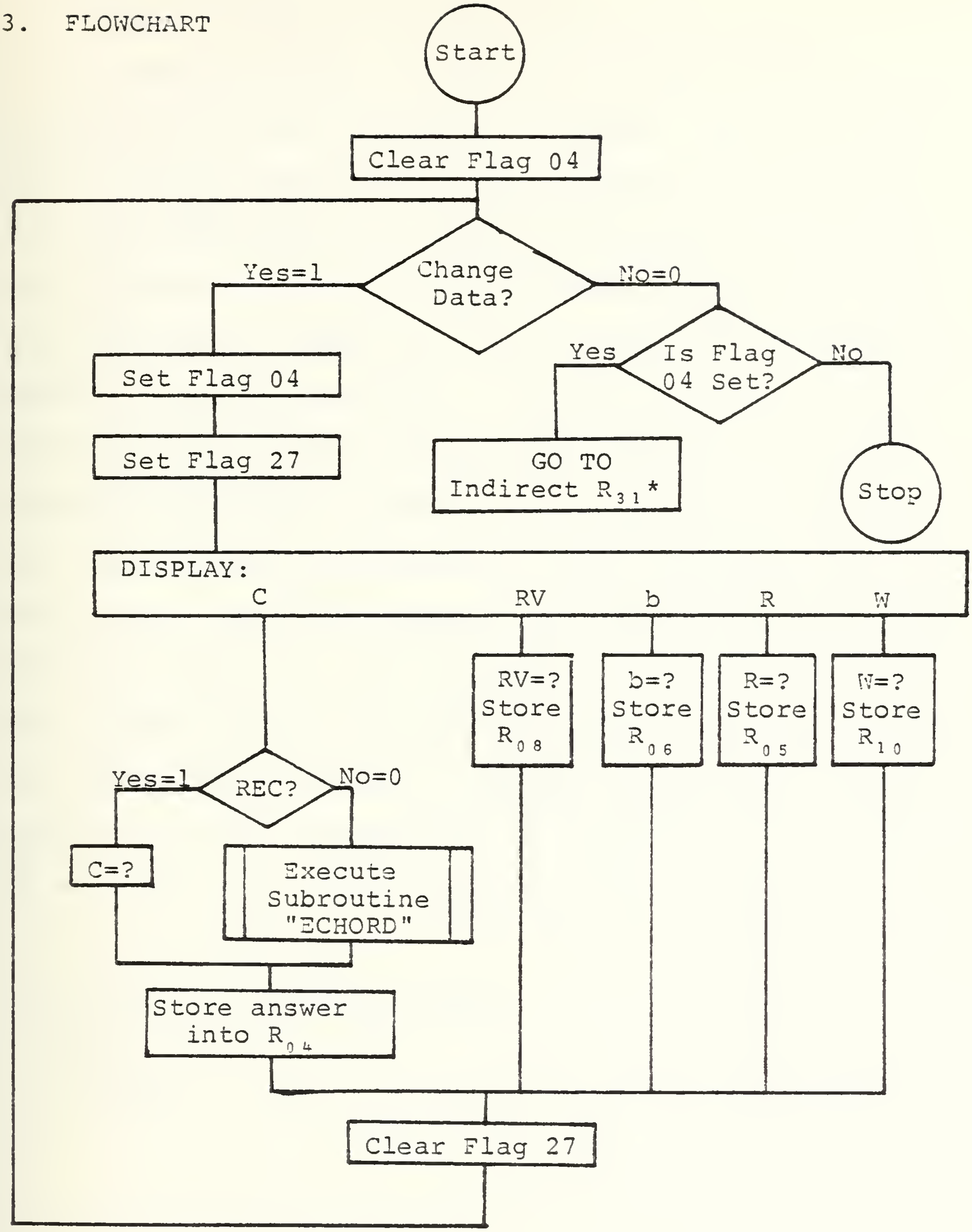
1. PURPOSE

This is a subroutine used by all main programs for expediting the change of input data. This subroutine is the last step in the main program listing before program termination. This subroutine allows for as many as five of the input variables to be quickly changed before returning to the top of the main program listing and initiating a new program operation. Upon examining the program listing for this subroutine, it will become quickly apparent to the user the ease of which this subroutine could be edited for other desired changes. Again, this is one of the purposes and obvious advantages of using subroutines throughout these programs.

2. EQUATIONS

none

3. FLOWCHART



* Returns to and reruns the main program with new data

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

No sample problem is given here because of the numerous examples that exist in the main programs. Note that when flag 27 is set, this automatically places the calculator into the [USER] mode. By pressing the key directly below the displayed variable in need of change, will next cause the calculator to prompt for the new data input. The new numeric value is then keyed in followed by [R/S]. The calculator will again prompt in the display for another change of data with: "CHANGE?". The user should remember that here as well as elsewhere in these programs, yes is 1 and no is 0. When all changes have been made and the answer no is received, the calculator will then return to the main program and begin execution with the new data. If on the initial time through, no changes are desired, and the answer no is given (notice from the flow chart that flag 04 has not been set), the main program will terminate operation.

5. PROGRAMS & SUBROUTINES USED

"CG"
"ECHORD"

6. PROGRAM LISTINGS

SUBROUTINE

```
01♦LBL "CG"
02 CF 04
03♦LBL 06
04 "CHANGE?"
05 PROMPT
06 X=0?
07 GTO 07
08 SF 04
09 SF 27
10 " C RV b R W"
11 PROMPT
12♦LBL A
13 "REC?"
14 PROMPT
15 X>0?
16 GTO 02
17 XEQ "ECHORD"
18 GTO 03
19♦LBL 02
20 "C=?"
21 PROMPT
22♦LBL 03
23 STO 04
24 GTO 05
25♦LBL B
26 "RV=?"
27 PROMPT
28 STO 08
29 GTO 05
30♦LBL C
31 "b=?"
32 PROMPT
33 STO 06
34 GTO 05
35♦LBL D
36 "R=?"
37 PROMPT
38 STO 05
39 GTO 05
40♦LBL E
41 "W=?"
42 PROMPT
43 STO 10
44♦LBL 05
45 CF 27
46 GTO 06
47♦LBL 07
48 FS? 04
49 GTO IND 31
50 END
```

PROFILE POWER

1. PURPOSE

This subroutine computes the profile power, P_o, required in terms of horsepower. Profile power is that power required to turn the rotor blades against their drag.

2. EQUATIONS

$$P_{o_h} = \frac{1}{8} \cdot \sigma_r \cdot \overline{C_{d_o}} \cdot \rho \cdot A_D \cdot V_T^3 \tag{14}$$

$$\mu = V_f / V_T \tag{15}$$

$$P_{o_f} / P_{o_h} = (1 + 4.25\mu^2) \tag{16}$$

where:

P_{o_h} is the profile power required to hover $\left[\frac{\text{ft-lb}}{\text{sec}}\right]$

P_{o_f} is the profile power required in forward flight $\left[\frac{\text{ft-lb}}{\text{sec}}\right]$

$\overline{C_{d_o}}$ is the average profile drag coefficient

A_D is the area of the rotor disc (ft^2)

V_T is the tip velocity (ft/sec)

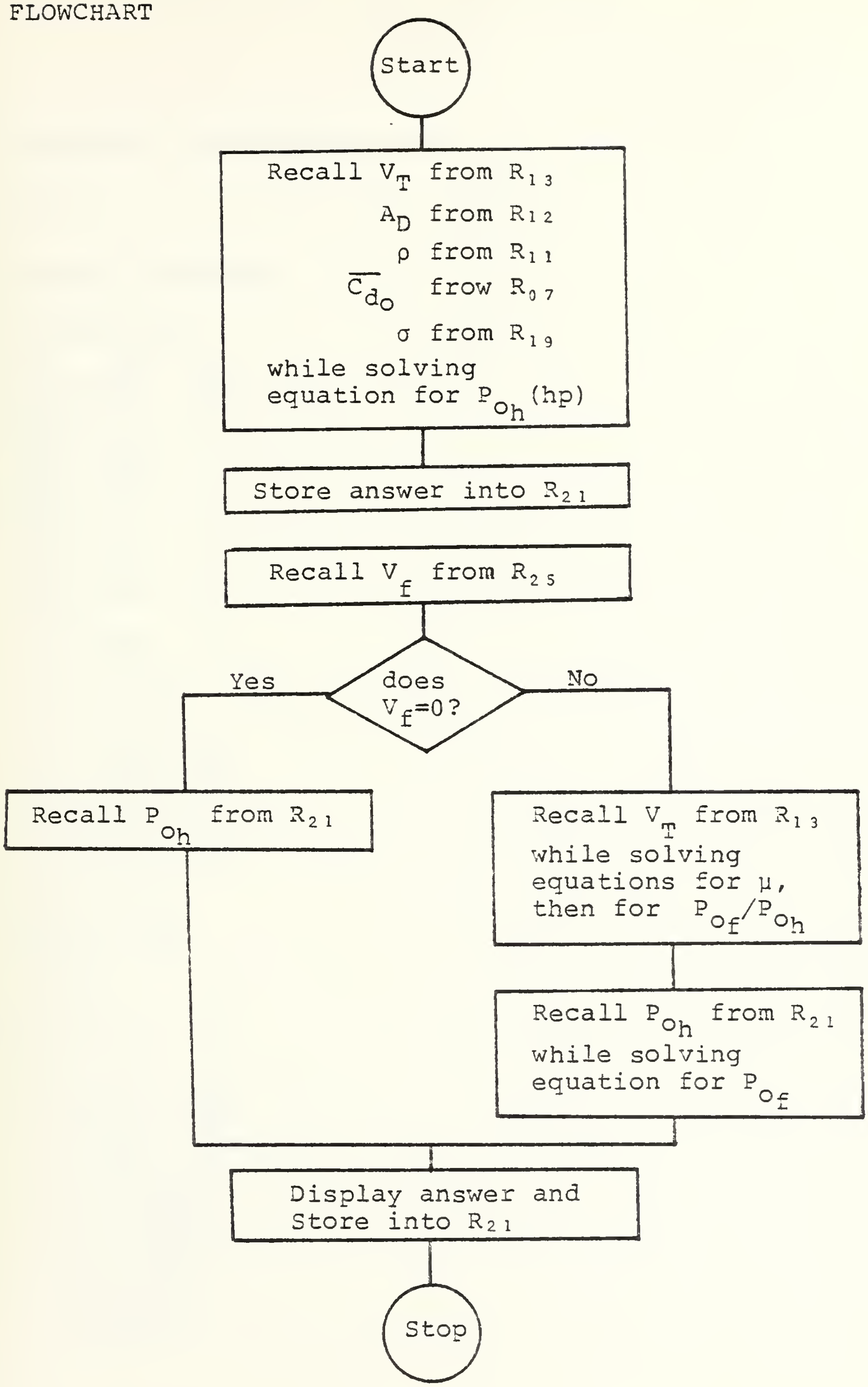
V_f is the forward velocity of the helicopter (ft/sec)

σ_r is the solidity of the rotor system

μ is the ratio of the rotor translational velocity to the velocity at the tip due to rotation

ρ is the density of the air $\left[\frac{\text{lb-sec}^2}{\text{ft}^4}\right]$

3. FLOWCHART


Start
Recall V_T from R_{13}
A_D from R_{12}
ρ from R_{11}
$\overline{C}_{d_o}$ frow R_{07}
σ from R_{19}
while solving equation for P_{o_h} (hp)
Store answer into R_{21}
Recall V_f from R_{25}
does $V_f=0$?
Yes
No
Recall P_{o_h} from R_{21}
Recall V_T from R_{13} while solving equations for μ, then for P_{o_f}/P_{o_h}
Recall P_{o_h} from R_{21} while solving equation for P_{o_f}
Display answer and Store into R_{21}
Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"PO"

6. PROGRAM LISTINGS

SUBROUTINE

```
01♦LBL "PO"
02 RCL 13
03 3
04 Y↑X
05 RCL 12
06 *
07 RCL 11
08 *
09 RCL 07
10 *
11 RCL 19
12 *
13 4400
14 /
15 STO 21
16 RCL 25
17 X=0?
18 GTO 08
19 RCL 13
20 /
21 X↑2
22 4.25
23 *
24 1
25 +
26 RCL 21
27 *
28 GTO 09
29♦LBL 08
30 RCL 21
31♦LBL 09
32 "PO="
33 PROMPT
34 VIEW X
35 STOP
36 STO 21
37 END
```

INDUCED POWER

1. PURPOSE

This subroutine computes the induced power, P_i, required in terms of horsepower. This subroutine deals only with hover and it takes into consideration both tip losses and ground effect. The induced power which produces a thrust equal to the weight (at hover) is equal to the product of the thrust and the inflow velocity. All of the main programs compute the inflow velocity peculiar to their flight conditions and will enter this subroutine at Label "PJ" or "TJ".

2. EQUATIONS

$$P_i = T \cdot v = T\sqrt{T/2\rho \cdot A_D} = \frac{T^{1.5}}{\sqrt{2\rho \cdot A_D}} \tag{17}$$

$$P_{i_{TL}} = \frac{P_i}{B} \tag{9}$$

$$\text{G.E. RATIO} = \frac{P_i}{P_{i_{OGE}}} \tag{12}$$

where:

T is the thrust which is equal to the weight, W (lb)

v is the induced velocity (ft/sec)

B is the tip loss factor

ρ is the density of the air $\left[\frac{\text{lb-sec}^2}{\text{ft}^4}\right]$

A_D is the disc area (ft^2)

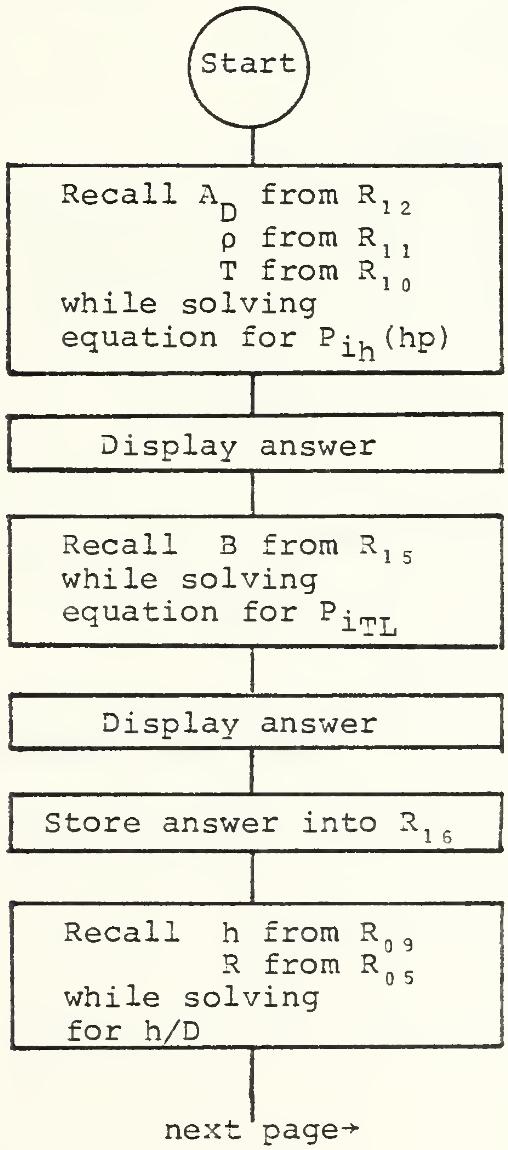
P_i is the induced power $\left[\frac{\text{ft-lb}}{\text{sec}}\right]$

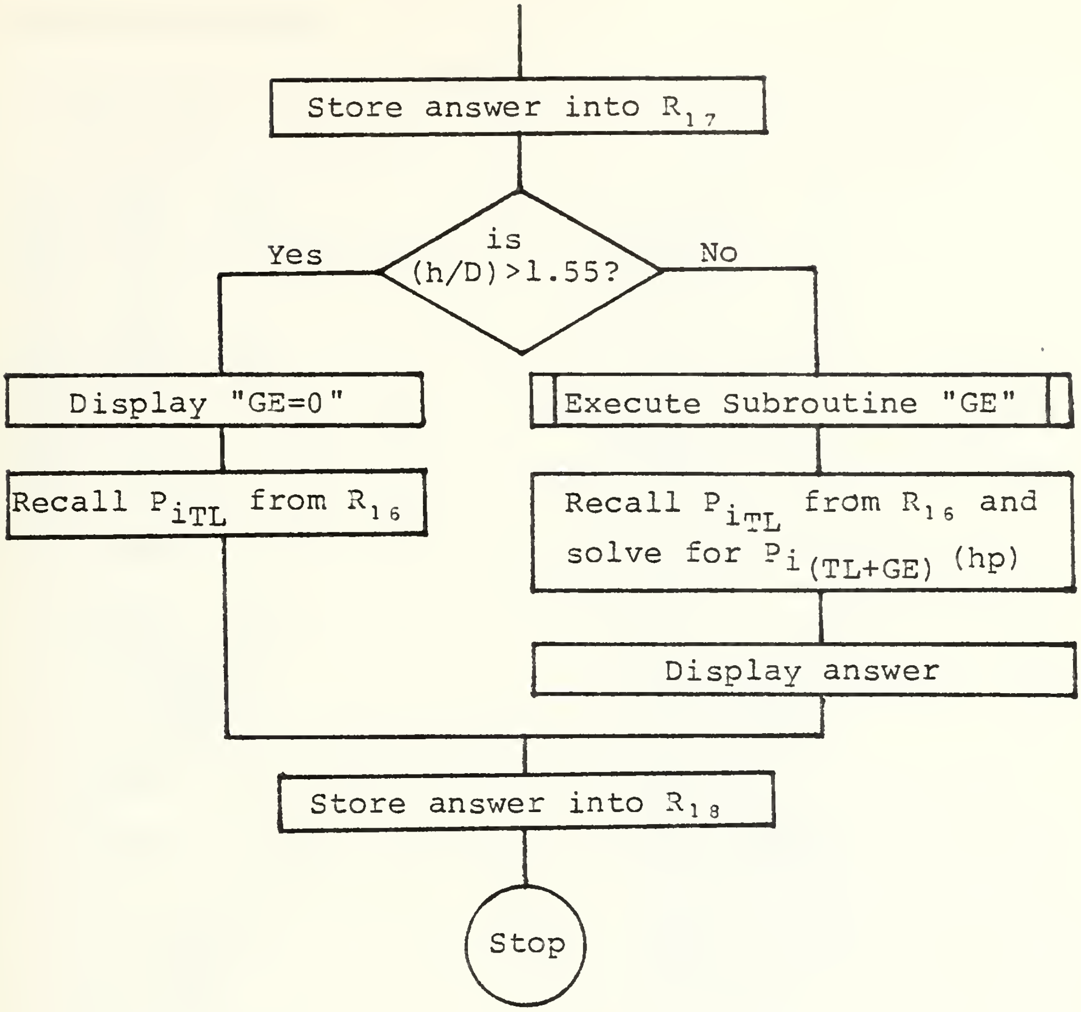
$P_{i_{TL}}$ is the induced power with tip losses $\left[\frac{\text{ft-lb}}{\text{sec}}\right]$

$P_{i_{OGE}}$ is the induced power under out-of-ground-effect conditions $\left[\frac{\text{ft-lb}}{\text{sec}}\right]$

G.E. RATIO is the ground effect ratio

3. FLOWCHART





4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS AND SUBROUTINES USED

"PI"
"GE"

6. PROGRAM LISTINGS

SUBROUTINE

```
01♦LBL "PI"
02 RCL 10
03 1.5
04 Y↑X
05 RCL 11
06 RCL 12
07 *
08 2
09 *
10 SQRT
11 /
12 550
13 /
14♦LBL "PJ"
15 "PI="
16 PROMPT
17 VIEW X
18 STOP
19 RCL 15
20 /
21♦LBL "TJ"
22 "PI<TL>=
"
23 PROMPT
24 VIEW X
25 STOP
26 STO 16
27 RCL 09
28 2
29 /
30 RCL 05
31 /
32 STO 17
33 1.55
34 -
35 X>0?
36 GTO 12
37 XEQ "GE"
38 RCL 16
39 *
40 "PI<TL+G
E>="
41 PROMPT
42 VIEW X
43 STOP
44 GTO 13
45♦LBL 12
46 "GE=0"
47 PROMPT
48 RCL 16
49♦LBL 13
50 STO 18
51 END
```

CLIMB POWER

1. PURPOSE

This subroutine computes the climb power, P_c, required in terms of horsepower.

2. EQUATIONS

$$P_c = T \cdot V_v \tag{18}$$

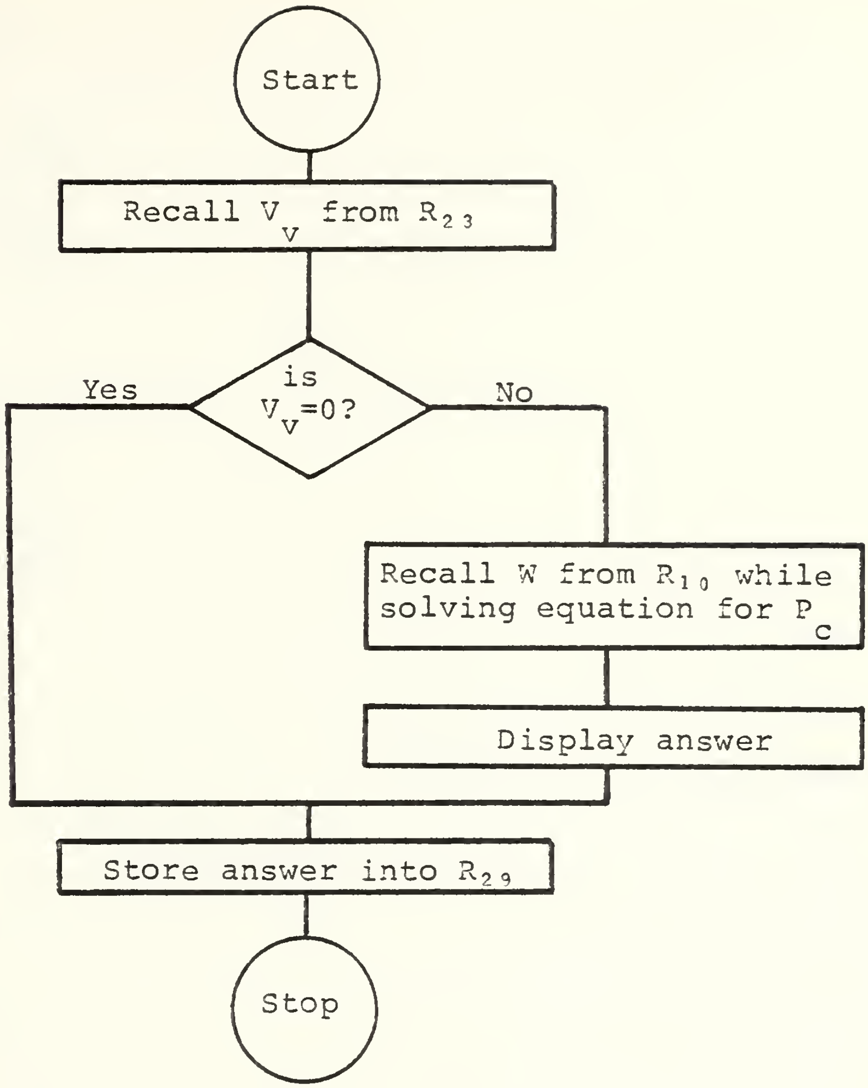
where:

P_c is climb power $\left[\frac{\text{ft-lb}_f}{\text{sec}}\right]$

T is the thrust which is equal to the weight, W (lb)

V_v is the vertical velocity (ft/sec)

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"PC"

6. PROGRAM LISTINGS

SUBROUTINE

```
♦LBL "PC"
RCL 23
X=0?
GTO 02
RCL 10
*
550
/
"PC="
PROMPT
VIEW X
STOP
♦LBL 02
STO 29
END
```

PARASITE POWER

1. PURPOSE

This subroutine computes the parasite power, P_p, required in terms of horsepower. As the helicopter proceeds from hover into forward flight, drag forces are created on the various components of the helicopter due to pressure drag and skin friction.

2. EQUATIONS

$$P_p = \tfrac{1}{2}\rho f_v V_v^{\,3} + \tfrac{1}{2}\rho f_f V_f^{\,3} \tag{19}$$

where:

P_p is the parasite power $\left[\dfrac{\text{ft-lb}_f}{\text{sec}}\right]$

f_v is the equivalent flat plate area for vertical flight (ft^2)

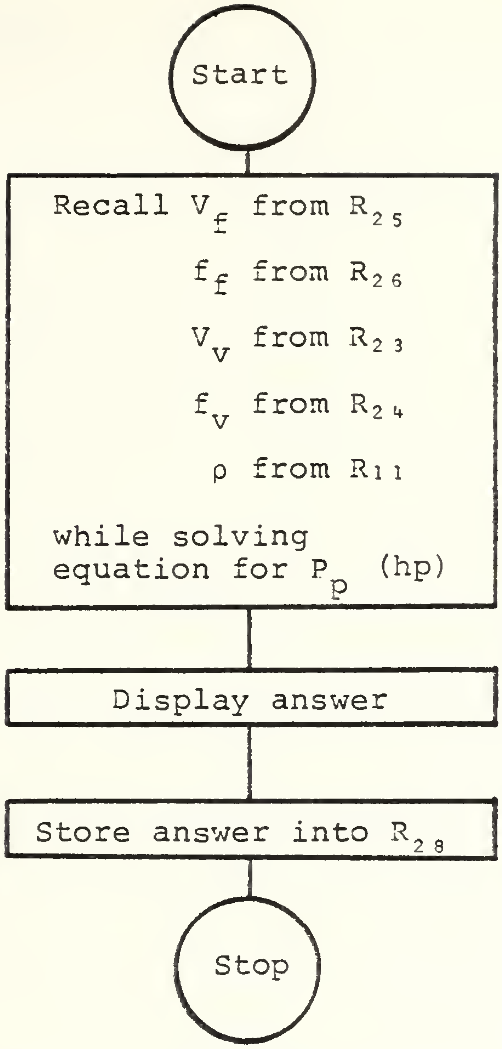
f_f is the equivalent flat plate area for forward flight (ft^2)

V_v is the vertical velocity (ft/sec)

V_f is the forward velocity (ft/sec)

ρ is the density of the air $\left[\dfrac{\text{lb}\cdot\text{sec}^2}{\text{ft}^4}\right]$

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"PP"

6. PROGRAM LISTINGS

SUBROUTINE

```
♦LBL "PP"
RCL 25
3
Y↑X
RCL 26
*
RCL 23
3
Y↑X
RCL 24
*
+
RCL 11
*
1100
/
"PP="
PROMPT
VIEW X
STOP
STO 28
END
```

TOTAL POWER

1. PURPOSE

This subroutine computes the total power, P_T, required for the main rotor in terms of horsepower.

2. EQUATIONS

$$P_T = P_i + P_o + P_c + P_p \tag{20}$$

wherw:

P_T is the total power required

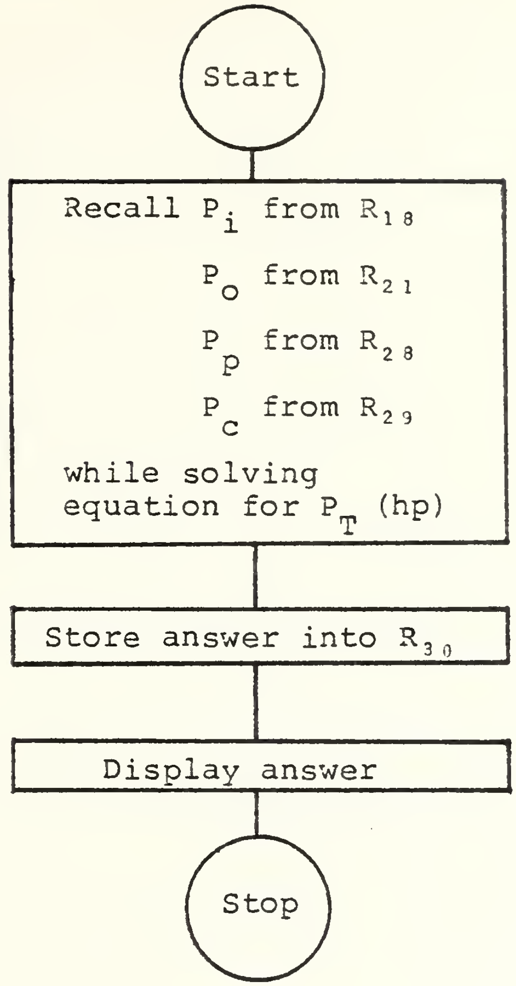
P_i is the induced power required

P_o is the profile power required

P_c is the climb power required

P_p is the parasite power required

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"PT"

6. PROGRAM LISTINGS

SUBROUTINE

```
01♦LBL "PT"
02 RCL 18
03 RCL 21
04 +
05 RCL 28
06 +
07 RCL 29
08 +
09 STO 30
10 "PT<MR>=
"
11 PROMPT
12 VIEW X
13 STOP
14 END
```

EQUIVALENT AREA

1. PURPOSE

This subroutine computes the equivalent area, A_e, with tip losses of a tandem rotor helicopter in terms of square feet.

2. EQUATIONS

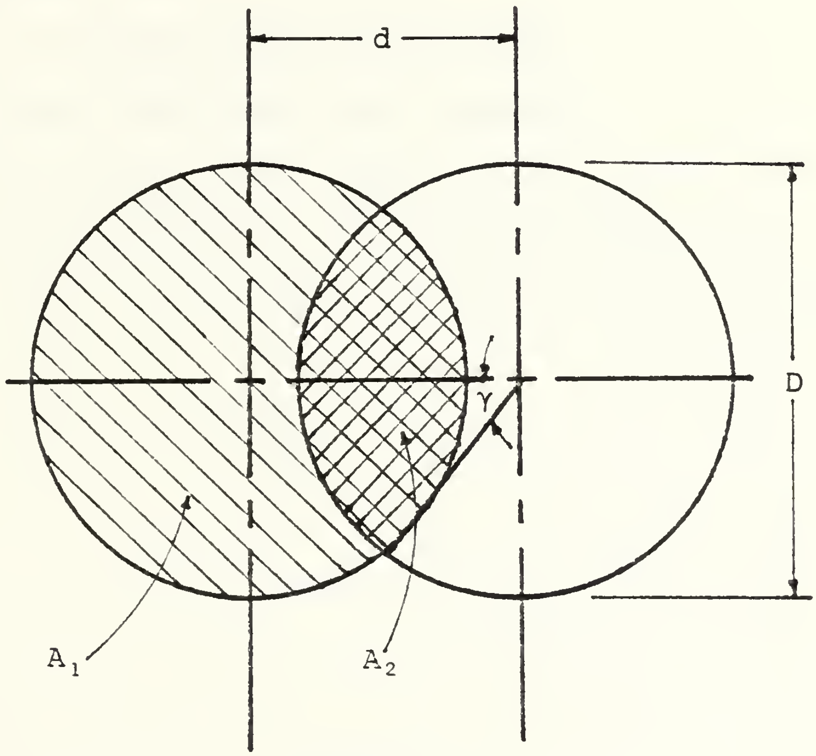


FIGURE 3
Planform View Of Overlapped Rotors [Ref. 3]

where:

$$\text{overlap} = 1 - d/D \tag{21}$$

$$S_R = d/R \tag{22}$$

$$\gamma = \cos^{-1}(1 - \text{overlap}) \tag{23}$$

$$A_o = 2A_1 + 2A_2 = 2\pi R^2 \tag{24}$$

$$A_e = 2A_1 + 2A_2 = A_o\left(1 - \left[\frac{\gamma - \sin\gamma\cos\gamma}{\pi}\right]\right) \tag{25}$$

where:

S_R is the shaft spacing ratio

A_o is the total combined area of the two rotor discs (ft^2)

A_e is the equivalent area (ft^2)

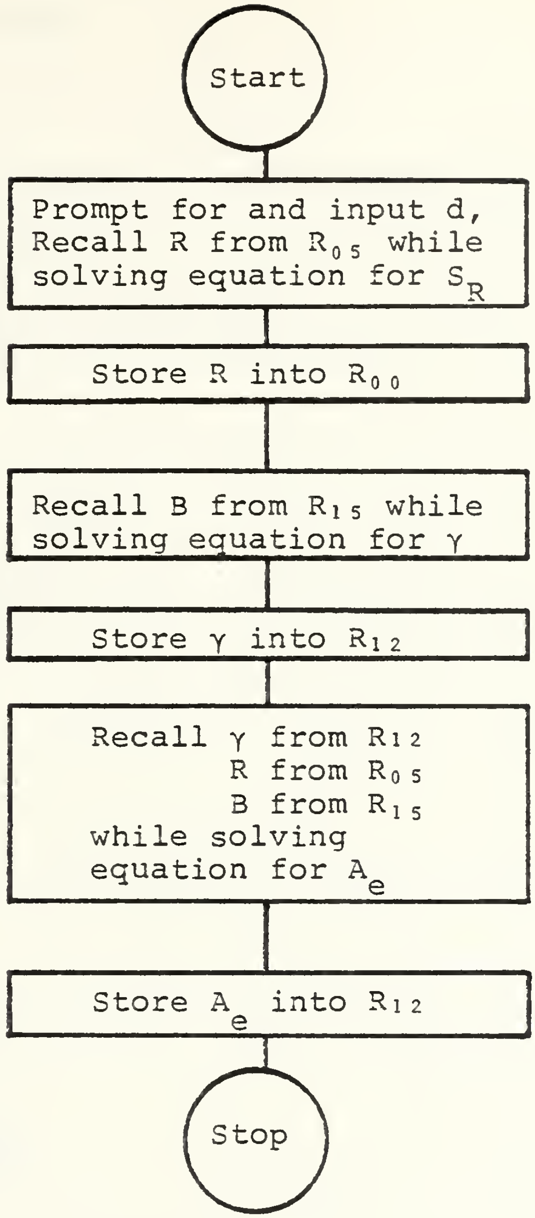
γ is the wake skew angle (radians)

R is the radius of the rotor system (ft)

D is the diameter of the rotor system (ft)

d is the distance between the rotor shafts (ft)

3. FLOWCHART



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"AE"

6. PROGRAM LISTINGS

SUBROUTINE

```
01♦LBL "AE"
02 "d=?"
03 PROMPT
04 RCL 05
05 /
06 STO 00
07 RCL 15
08 /
09 2
10 /
11 RAD
12 ACOS
13 STO 12
14 COS
15 RCL 12
16 SIN
17 *
18 CHS
19 RCL 12
20 +
21 PI
22 /
23 CHS
24 1
25 +
26 2
27 *
28 PI
29 *
30 RCL 05
31 RCL 15
32 *
33 X↑2
34 *
35 STO 12
36 DEG
37 END
```

TANDEM ROTOR INDUCED POWER

1. PURPOSE

This subroutine computes the induced power required for a tandem rotor helicopter in terms of horsepower. This subroutine will compute both the induced power at a hover, P_{i_h}, and the induced power in forward flight, P_{i_f}.

2. EQUATIONS

$$P_{i_h} = \frac{T^{1.5}}{\sqrt{2 \cdot \rho \cdot A_e}} \cdot K \tag{26}$$

$$K = 1.46 - 0.253 S_R \tag{27}$$

$$P_{i_f} = P_{i_h} \cdot K_u \tag{28}$$

$$K_u = 1 + d_f/2 \tag{29}$$

$$S_R = d/R \tag{22}$$

$$\gamma = \tan^{-1}\left(\frac{1.5\ T_f}{2 \cdot \rho \cdot A_f \cdot V_f^2}\right) \tag{30}$$

$$d_f = \frac{\sqrt{1 + S_R^2} + S_R \cdot \cos\gamma}{\sqrt{1 + S_R^2}\ (1 + S_R^2 \cdot \sin^2\gamma)} \tag{31}$$

where:

P_{i_h} is the induced power at a hover $\left[\frac{\text{ft-lb}_f}{\text{sec}}\right]$

P_{i_f} is the induced power in forward flight $\left[\frac{ft\text{-}lb_f}{sec}\right]$

A_e is the effective area (ft^2)

A_f is the area of the forward rotor disc (ft^2)

d_f is the induced power correction factor

K_u is the forward flight correction factor

S_R is the rotor shaft spacing ratio

T_f is the thrust of the forward rotor which is usually equal to ½W, the weight (lb_f)

V_f is the forward velocity (ft/sec)

K is the ratio of the induced power at a hover for a single rotor helicopter as compared to a tandem

d is the distance between the rotor shafts (ft)

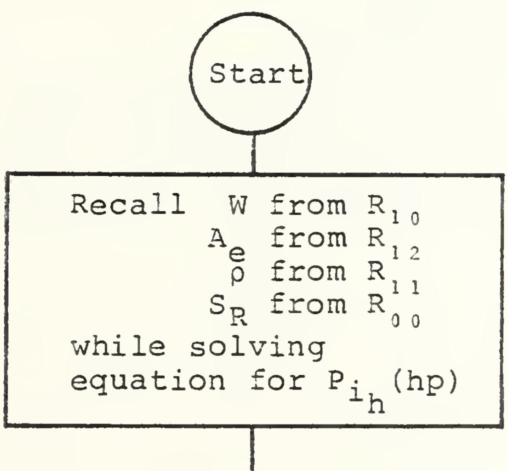
R is the radius of the rotor system (ft)

T is the thrust which is equal to the weight, W (lb_f)

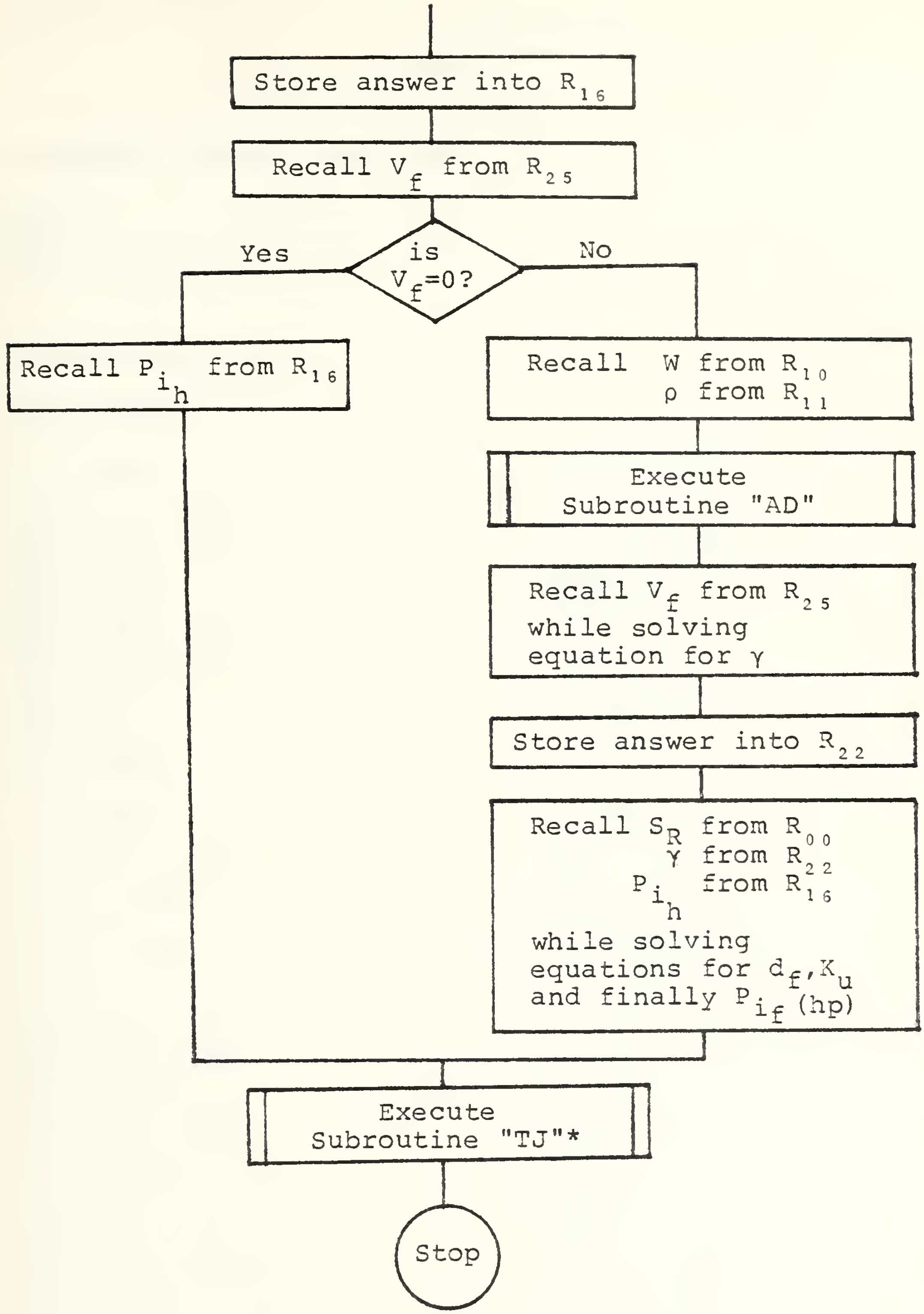
γ is the wake skewing angle

ρ is the density of the air $\left[\frac{lb\text{-}sec^2}{ft^4}\right]$

3. FLOWCHART



next page→



*enters Subroutine "PI" at label "TJ"

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

none

5. PROGRAMS & SUBROUTINES USED

"PIT"
"AD"
"PI" at label "TJ"

6. PROGRAM LISTINGS

SUBROUTINE

```
◆LBL "PIT"
RCL 10
1.5
Y↑X
RCL 12
RCL 11
*
2
*
SQRT
/
550
/
RCL 00
-.253
*
1.46
+
*
STO 16
RCL 25
X=0?
GTO 01
RCL 10
.375
*
RCL 11
/
XEQ "AD"
/
RCL 25
X↑2
/
ATAN
STO 22
SIN
X↑2
RCL 00
X↑2
*
1
+
RCL 00
X↑2
1
+
SQRT
STO 19
*
1/X
RCL 22
COS
RCL 00
*
RCL 19
+
*
2
/
1
+
RCL 16
*
GTO 02
◆LBL 01
RCL 16
◆LBL 02
XEQ "TJ"
END
```

APPENDIX D

MAIN PROGRAMS

This appendix consists of the main programs of this programming effort. The major ingredients of these programs are the subroutines found in the preceding two appendices. These main programs compute the various power requirements for hovering flight, forward (straight and level) flight, vertical flight, and forward climbing flight all for a single rotor helicopter; also tailrotor power requirements; autorotative flight; tandem rotor hovering and forward flight power requirements; and finally a short program to check several of the critical flight parameters.

HOVER

1. PURPOSE

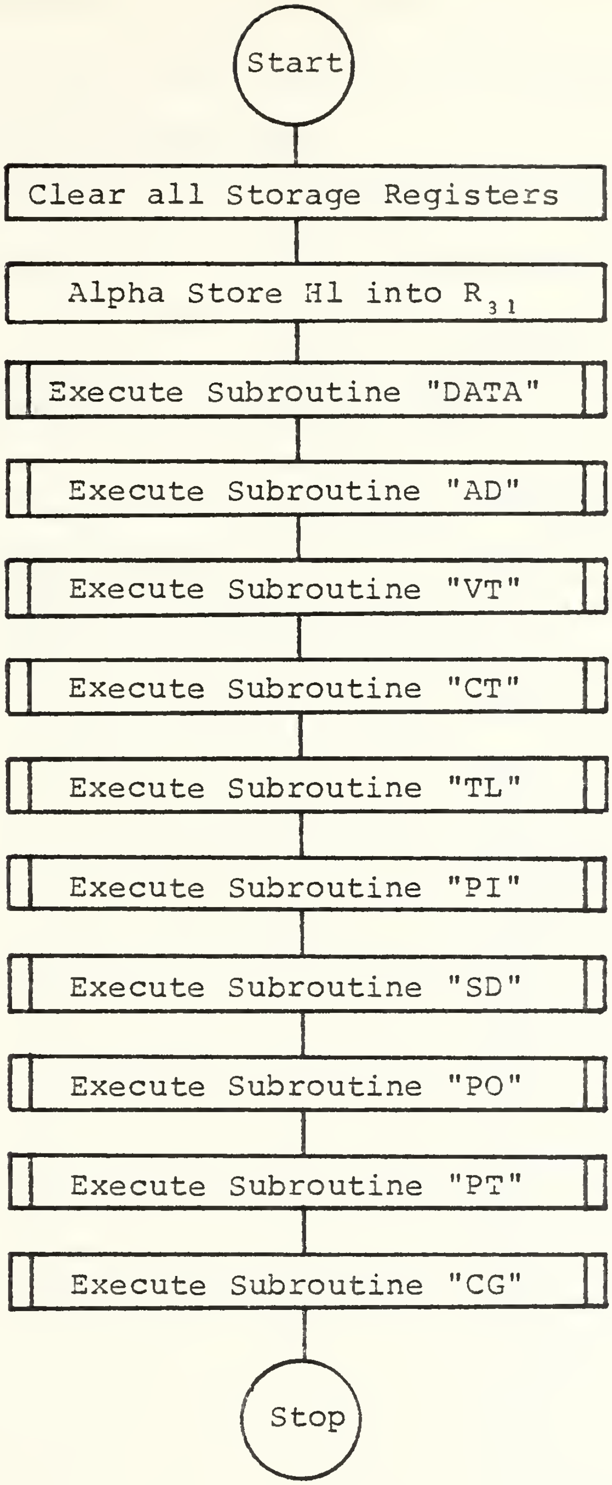
This main program computes the various power requirements in terms of horsepower for hovering flight. The various calculated power requirements are displayed as follows:

Display:	Explanation:
PI=	induced power
PI(TL)=	induced power with tip losses
PI(TL+GE)=	induced power with tip losses plus ground effect
PO=	profile power
PT(MR)=	total power for the main rotor

2. EQUATIONS

No equations are found in the actual program itself. Consult the various subroutine listings for the equations used.

3. FLOWCHART


Start
Clear all Storage Registers
Alpha Store H1 into R_{31}
Execute Subroutine "DATA"
Execute Subroutine "AD"
Execute Subroutine "VT"
Execute Subroutine "CT"
Execute Subroutine "TL"
Execute Subroutine "PI"
Execute Subroutine "SD"
Execute Subroutine "PO"
Execute Subroutine "PT"
Execute Subroutine "CG"
Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the hover power requirements for an OH-58C, Kiowa, under the following conditions:

C = 1.086 ft	Ω = 354 RPM → 37.068 rads/sec
R = 17.7 ft	h = 25 ft
b = 2	D.A. = 1,000 ft
W = 3,000 lbs	$\bar{C}_{d_o}$ = .008

Keystrokes:	Display:
[XEQ] [ALPHA] HOVER [ALPHA]	REC?
(Rectangular Blade? 1 is Yes, 0 is No)	
1 [R/S]	C=?
1.086 [R/S]	R=?
17.7 [R/S]	b=?
2 [R/S]	CdO=?
.008 [R/S]	RV=?
37.068 [R/S]	H=?
25 [R/S]	W=?
3,000 [R/S]	D.A.=?
1,000 [R/S]	PI=
[R/S]	140.16
[R/S]	PI(TL)=
[R/S]	145.87
[R/S]	PI(TL+GE)=
[R/S]	139.21
[R/S]	PO=

[R/S]	45.57
[R/S]	PT(MR)=
[R/S]	184.77
[R/S]	CHANGE?

(Change Data? 1 is Yes, 0 is No)

1 [R/S]	C RV b R W

It is desired at this point to increase the weight of this helicopter to 3,200 lbs (maximum gross weight). To observe what effect this change will have on the hover power requirements, press the key on the calculator keyboard directly beneath the variable in need of change. In this case the [LN] key is directly beneath the W in the display:

[LN]	W=?
3,200 [R/S]	CHANGE?

(Any Further Changes? 1 is Yes, 0 is No)

0 [R/S]	PI=
[R/S]	154.41
[R/S]	PI(TL)=
[R/S]	160.92
[R/S]	PI(TL+GE)=
[R/S]	153.56
[R/S]	PO=
[R/S]	45.57
[R/S]	PT(MR)=
[R/S]	199.13
[R/S]	CHANGE?

0 [R/S]	0.00

Now, using the same OH-58C at the new weight of 3,200 lbs find the hover power requirements with the rotor system height above the ground, h, equal to 60 ft.

Keystrokes:	Display:
[R/S]	REC?
1 [R/S]	C=?
1.086 [R/S]	R=?
17.7 [R/S]	b=?
2 [R/S]	CdO=?
.008 [R/S]	RV=?
37.068 [R/S]	H=?
60 [R/S]	W=?
3,200 [R/S]	D.A.=?
1,000 [R/S]	PI=
[R/S]	154.41
[R/S]	PI(TL)=
[R/S]	160.92
[R/S]	GE=0

(Ground effect is now equal to zero, the helicopter is hovering out of ground effect.)

[R/S]	PO=
[R/S]	45.57
[R/S]	PT(MR)=
[R/S]	206.48

[R/S]	CHANGE?
0 [R/S]	0.00

5. PROGRAMS & SUBROUTINES USED

"AD"	"ECHORD"	"PT"
"CG"	"GE"	"SD"
"CT"	"HOVER"	"TL"
"DATA"	"PI"	"VT"
"DN"	"PO"	

6. PROGRAM LISTINGS

PROGRAM

```
 01♦LBL "HOV
ER"
 02 CLRG
 03 "H1"
 04 ASTO 31
 05 XEQ "DAT
A"
 06♦LBL "H1"
 07 XEQ "AD"
 08 XEQ "VT"
 09 XEQ "CT"
 10 XEQ "TL"
 11 XEQ "PI"
 12 XEQ "SD"
 13 XEQ "PO"
 14 XEQ "PT"
 15 XEQ "CG"
 16 END
```

FORWARD FLIGHT

1. PURPOSE

This main program computes the various power requirements in terms of horsepower for forward (straight and level) flight. If the forward flight velocity, V_f, is entered as zero, this program will also calculate the various hover power requirements. The various calculated power requirements are displayed as follows:

Display:	Explanation:
PI=	induced power
PI(TL)=	induced power with tip losses
PI(TL+GE)=	induced power with tip losses plus ground effect
PO=	profile power
PP=	parasite power
PT(MR)=	total power for the main rotor

2. EQUATIONS

$$V_{f\ (ft/sec)} = V_{f\ (kts)} \cdot (1.68894) \tag{32}$$

$$P_i = T \cdot v_{i_T} = T \cdot \left\{ -\frac{V_f^2/v_i^2}{2} + \sqrt{(V_f^2/2v_i^2)^2 + 1} \right\}^{\frac{1}{2}} \cdot v_i \tag{33}$$

where:

T is the thrust which is equal to the weight, W (lb_f)

V_f is the forward velocity (ft/sec)

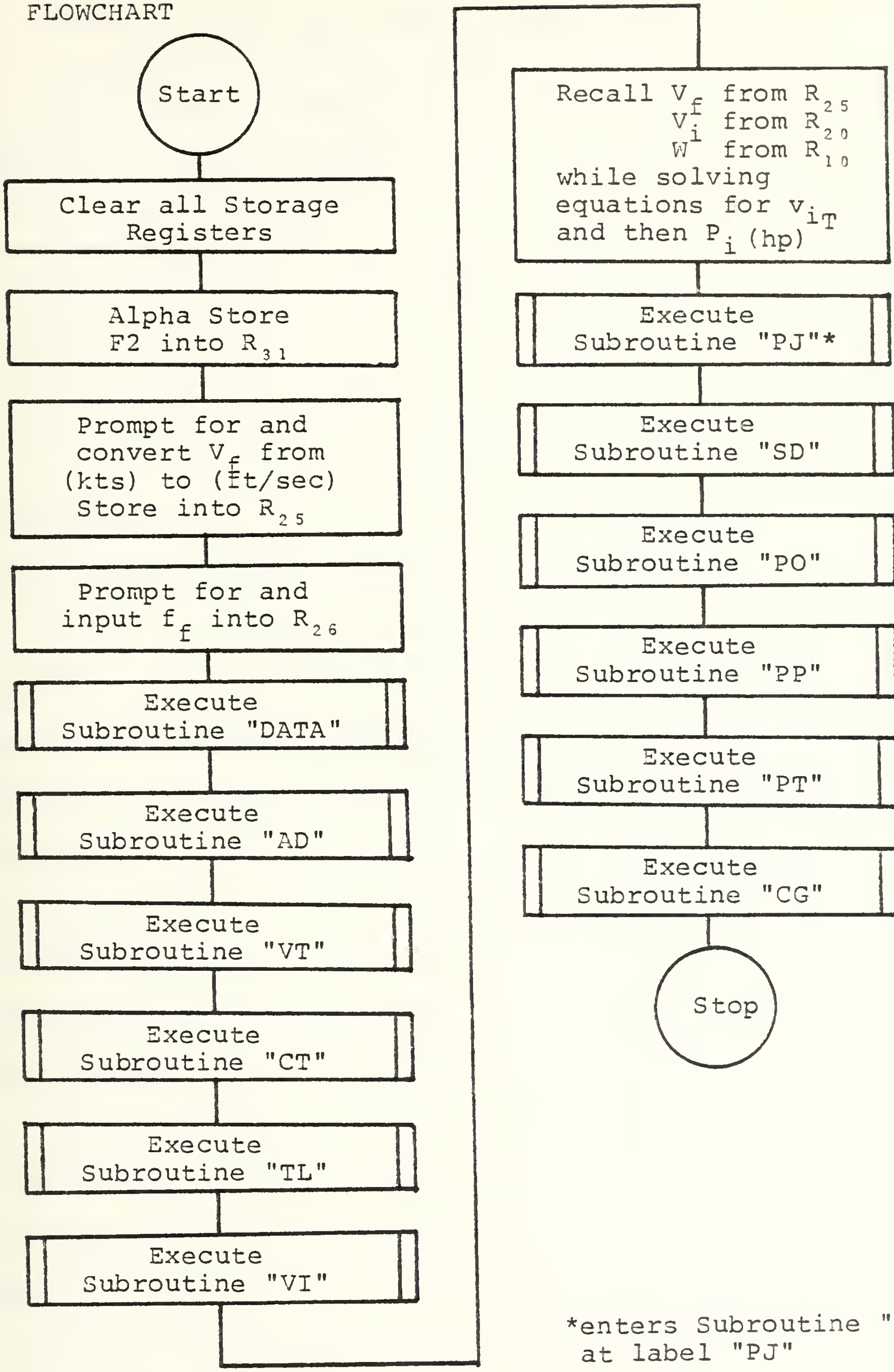
v_i is the induced velocity at a hover (ft/sec)

P_i is the induced power required $\left[\frac{ft\text{-}lb_f}{sec}\right]$

v_{i_T} is the thrust component of the induced velocity vector (ft/sec)

No other equations are found in the actual program itself. Consult the various subroutine listings for the equations used.

3. FLOWCHART



*enters Subroutine "PI" at label "PJ"

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the forward (straight and level) flight power requirements for an OH-6A, Cayuse, under the following conditions:

$C = 0.57$ ft	$\Omega = 470$ RPM $\rightarrow$ 49.215 rads/sec
$R = 13.165$ ft	$\bar{C}_{d_o} = .009$
$b = 4$	D.A. = 500 ft
$W = 2{,}250$ lbs	$V_f = 90$ kts
$h = 100$ ft	$f_f = 5.0$ ft^2

Keystrokes:	Display:
[XEQ] [ALPHA] FORFLT [ALPHA]	FOR V=?
90 [R/S]	F.P.A.(FF)=?
5 [R/S]	REC?
(Rectangular Blade? 1 is Yes, 0 is No)	
1 [R/S]	C=?
.57 [R/S]	R=?
13.165 [R/S]	b=?
4 [R/S]	CdO=?
.009 [R/S]	RV=?
49.215 [R/S]	H=?
100 [R/S]	W=?
2,250 [R/S]	D.A.=?
500 [R/S]	PI=
[R/S]	23.72
[R/S]	PI(TL)=
[R/S]	24.28

[R/S]	GE=0
[R/S]	PO=
[R/S]	48.27
[R/S]	PP=
[R/S]	37.39
[R/S]	PT(MR)=
[R/S]	109.94
[R/S]	CHANGE?

(Change Data? 1 is Yes, 0 is No)

1 [R/S]	C RV b R W

It is desired at this point to decrease the rotor radius from 13.165 ft to 12.665 ft. To observe what effect this change will have on the forward flight horsepower requirements, press the key on the calculator keyboard directly beneath the variable in need of change. In this case the [LOG] key is directly beneath the R in the display:

[LOG]	R=?
12.665 [R/S]	CHANGE?

(Any Further Changes? 1 is Yes, 0 is No)

0 [R/S]	PI=
[R/S]	25.63
[R/S]	PI(TL)=
[R/S]	26.28
[R/S]	GE=0
[R/S]	PO=
[R/S]	41.97

[R/S]	PP=
[R/S]	37.39
[R/S]	PT(MR)=
[R/S]	105.64
[R/S]	CHANGE?
0 [R/S]	0.00

Find the hovering flight power requirements for the same OH-6A under the original conditions with the only difference being $V_f = 0$.

Keystrokes:	Display:
[R/S]	FOR V=?
0 [R/S]	F.P.A.(FF)=?
5 [R/S]	REC?
1 [R/S]	C=?
.57 [R/S]	R=?
13.165 [R/S]	b=?
4 [R/S]	CdO=?
.009 [R/S]	RV=?
49.215 [R/S]	H=?
100 [R/S]	W=?
2,250 [R/S]	D.A.=?
500 [R/S]	PI=
[R/S]	121.50
[R/S]	PI(TL)=
[R/S]	124.35

[R/S]	GE=0
[R/S]	PO=
[R/S]	39.12
[R/S]	PP=
[R/S]	0.00
[R/S]	PT(MR)=
[R/S]	163.47
[R/S]	CHANGE?
0 [R/S]	0.00

note - When program "HOVER" is executed for this case, the outputs are identical. Examination of equation 33 with $V_f = 0$, readily explains the reason for the identical results.

5. PROGRAMS & SUBROUTINES USED

"AD"	"FORFLT"	"SD"
"CG"	"GE"	"TL"
"CT"	"PI" at label "PJ"	"VI"
"DATA"	"PO"	"VT"
"DN"	"PP"	
"ECHORD"	"PT"	

6. PROGRAM LISTINGS

PROGRAM

```
 01♦LBL "FOR
FLT"
 02 CLRG
 03 "F2"
 04 ASTO 31
 05 "FOR V=?
"
 06 PROMPT
 07 1.68894
 08 *
 09 STO 25
 10 "F.P.A.<
FF>=?"
 11 PROMPT
 12 STO 26
```

```
 13 XEQ "DAT
A"
 14♦LBL "F2"
 15 XEQ "AD"
 16 XEQ "VT"
 17 XEQ "CT"
 18 XEQ "TL"
 19 XEQ "VI"
 20 RCL 25
 21 RCL 20
 22 /
 23 X↑2
 24 2
 25 /
 26 STO 00
 27 X↑2
 28 1
 29 +
 30 SQRT
 31 RCL 00
 32 -
 33 SQRT
 34 RCL 20
 35 *
 36 RCL 10
 37 *
 38 550
 39 /
 40 XEQ "PJ"
 41 XEQ "SD"
 42 XEQ "PO"
 43 XEQ "PP"
 44 XEQ "PT"
 45 XEQ "CG"
 46 END
```

VERTICAL FLIGHT

1. PURPOSE

This main program computes the various power requirements in terms of horsepower for vertical flight (vertical ascent). If the vertical velocity, V_V, is entered as zero, this program will also calculate the various hover power requirements. The various calculated power requirements are displayed as follows:

Display:	Explanation:
PI=	induced power
PI(TL)=	induced power with tip losses
PI(TL+GE)=	induced power with tip losses plus ground effect
PO=	profile power
PP=	parasite power
PC=	climb power
PT(MR)=	total power for the main rotor

2. EQUATIONS

$$V_V \text{ (ft/sec)} = V_V \text{ (ft/min)} \cdot 60 \quad (34)$$

$$v_V = -\frac{V_V}{2} + \sqrt{(V_V/2)^2 + {v_{i_h}}^2} \quad (35)$$

$$P_{i_c} = T \cdot v_V \quad (36)$$

where:

T is the thrust which is equal to the weight, W (lb_f)

v_v is the induced velocity due to pumping in a vertical climb (ft/sec)

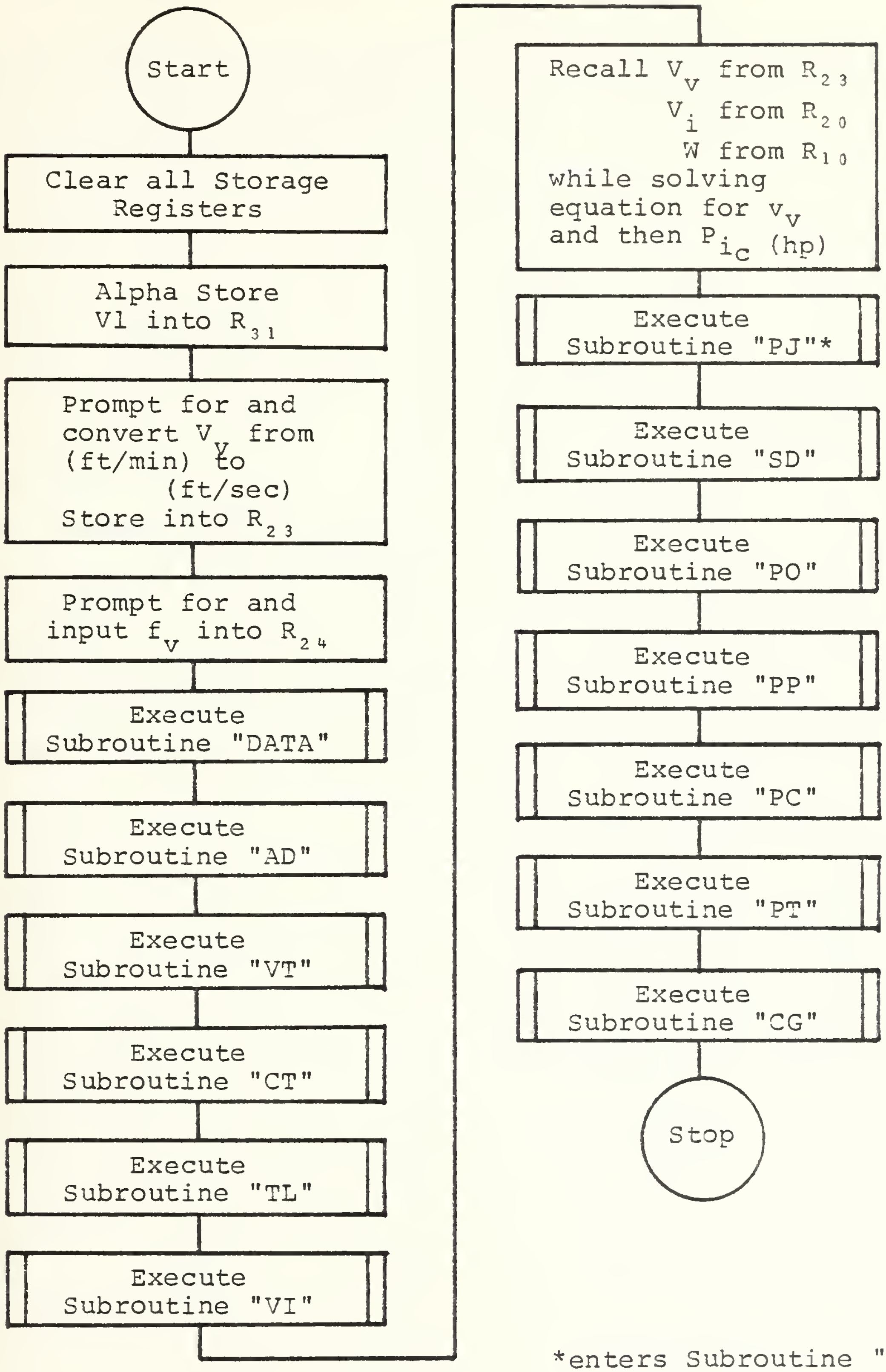
V_v is the steady rate of climb velocity (ft/sec)

v_{i_h} is the induced velocity at a hover (ft/sec)

P_{i_c} is the induced power required to climb $\left[\frac{ft\text{-}lb_f}{sec}\right]$

No other equations are found in the actual program itself. Consult the various subroutine listings for the equations used.

3. FLOWCHART



*enters Subroutine "PI" at label "PJ"

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the vertical flight power requirements for an SH-3H, Sea King, under the following flight conditions:

$C = 1.52$ ft	$\bar{C}_{d_o} = .0095$
$R = 31$ ft	D.A. = 100 ft
$b = 5$	$V_v = 1{,}000$ ft/sec
$W = 18{,}000$ lbs	$f_v = 360$ ft^2
$h = 100$ ft	$\Omega = 203$ RPM $\rightarrow$ 21.257 rads/sec

Keystrokes:	Display:
[XEQ] [ALPHA] VERFLT [ALPHA]	VERT V=?
1,000 [R/S]	F.P.A.(VF)=?
360 [R/S]	REC?
(Rectangular Blade? 1 is Yes, 0 is No)	
1 [R/S]	C=?
1.52 [R/S]	R=?
31 [R/S]	b=?
5 [R/S]	CdO=?
.0095 [R/S]	RV=?
21.257 [R/S]	H=?
100 [R/S]	W=?
18,000 [R/S]	D.A.=?
100 [R/S]	PI=
[R/S]	919.60
[R/S]	PI(TL)=
[R/S]	939.83

[R/S]	GE=0
[R/S]	PO=
[R/S]	344.97
[R/S]	PP=
[R/S]	3.59
[R/S]	PC=
[R/S]	545.45
[R/S]	PT(MR)=
[R/S]	1,833.84
[R/S]	CHANGE?

(Change Data? 1 is Yes, 0 is No)

1 [R/S]	C RV b R W

It is desired at this point to taper the rotor blades. The new main rotor blade dimensions are:

$C_0 = 1.52$

$C_1 = 0.76$

$a = .90$

To observe what effect this change will have on the vertical flight power requirements, press the key on the calculator keyboard directly beneath the variable in need of change. In this case the [Σ+] key is directly beneath the C in the display:

[Σ+]	REC?
0 [R/S]	C0=?
1.52 [R/S]	C1=?
.76 [R/S]	a=?

.9 [R/S]	CE=1.413

(The new Equivalent Chord is 1.413 ft)

[R/S]	CHANGE?

(Any Further Changes? 1 is Yes, 0 is No)

0 [R/S]	PI=
[R/S]	919.595
[R/S]	PI(TL)=
[R/S]	939.828
[R/S]	GE=0
[R/S]	PO=
[R/S]	320.776
[R/S]	PP=
[R/S]	3.591
[R/S]	PC=
[R/S]	545.455
[R/S]	PT(MR)=
[R/S]	1,809.649
[R/S]	CHANGE?
0 [R/S]	0.000

Find the hovering flight power requirements for the same SH-3H under the original conditions with the only difference being $V_v = 0$.

Keystrokes:	Display:
[R/S]	VERT V=?
0 [R/S]	F.P.A.(VF)=?

360 [R/S]	REC?
1 [R/S]	C=?
1.52 [R/S]	R=?
31 [R/S]	b=?
5 [R/S]	CdO=?
.0095 [R/S]	RV=?
21.257 [R/S]	H=?
100 [R/S]	W=?
18,000 [R/S]	D.A.=?
100 [R/S]	PI=
[R/S]	1,160.712
[R/S]	PI(TL)=
[R/S]	1,186.250
[R/S]	GE=0
[R/S]	PO=
[R/S]	344.966
[R/S]	PP=
[R/S]	0.000
[R/S]	PT(MR)=
[R/S]	1,531.217
[R/S]	CHANGE?
0 [R/S]	0.000

note - When program "HOVER" is executed for this case, the outputs are identical. Examination of equations 35 and 36 with $V_v = 0$, readily explains the reason for the identical results.

5. PROGRAMS & SUBROUTINES USED

"AD"	"GE"	"SD"
"CG"	"PC"	"TL"
"CT"	"PI" at label "PJ"	"VERFLT"
"DATA"	"PO"	"VI"
"DN"	"PP"	"VT"
"ECHORD"	"PT"	

6. PROGRAM LISTINGS

PROGRAM

```
 01◆LBL "VER
FLT"
 02 CLRG
 03 "V1"
 04 ASTO 31
 05 "VERT V=
?"
 06 PROMPT
 07 60
 08 /
 09 STO 23
 10 "F.P.A.<
VF>=?"
 11 PROMPT
 12 STO 24
 13 XEQ "DAT
A"
 14◆LBL "V1"
 15 XEQ "AD"
 16 XEQ "VT"
 17 XEQ "CT"
 18 XEQ "TL"
 19 XEQ "VI"
 20 RCL 23
 21 2
 22 /
 23 RCL 20
 24 /
 25 STO 00
 26 X↑2
 27 1
 28 +
 29 SQRT
 30 RCL 00
 31 -
 32 RCL 20
 33 *
 34 RCL 10
 35 *
 36 550
 37 /
 38 XEQ "PJ"
 39 XEQ "SD"
 40 XEQ "PO"
 41 XEQ "PP"
 42 XEQ "PC"
 43 XEQ "PT"
 44 XEQ "CG"
 45 END
```

1. PURPOSE

This main program computes the various power requirements in terms of horsepower for forward climbing flight. If the vertical velocity, V_v, is entered as zero, this program will compute the various power requirements for forward (straight and level) flight. If the forward velocity, V_f, is entered as zero, this program will compute the various power requirements for vertical flight. If both the vertical velocity, V_v, and the forward velocity, V_f, are entered as zero, this program will compute the various power requirements for hovering flight. The various calculated power requirements are displayed as follows:

Display:	Explanation:
PI=	induced power
PI(TL)=	induced power with tip losses
PI(TL+GE)=	induced power with tip losses plus ground effect
PO=	profile power
PP=	parasite power
PC=	climb power
PT(MR)=	total power for the main rotor

2. EQUATIONS

$$V_{f\ (ft/sec)} = V_{f\ (kts)} \cdot (1.68894) \qquad (32)$$

$$P_i = T \cdot v_{i_T} \tag{33}$$

$$V_{v\ (ft/sec)} = V_{v\ (ft/min)} \cdot 60 \tag{34}$$

where:

T is the thrust which is equal to the weight, W (lb_f)

P_i is the induced power $\frac{ft\text{-}lb_f}{sec}$

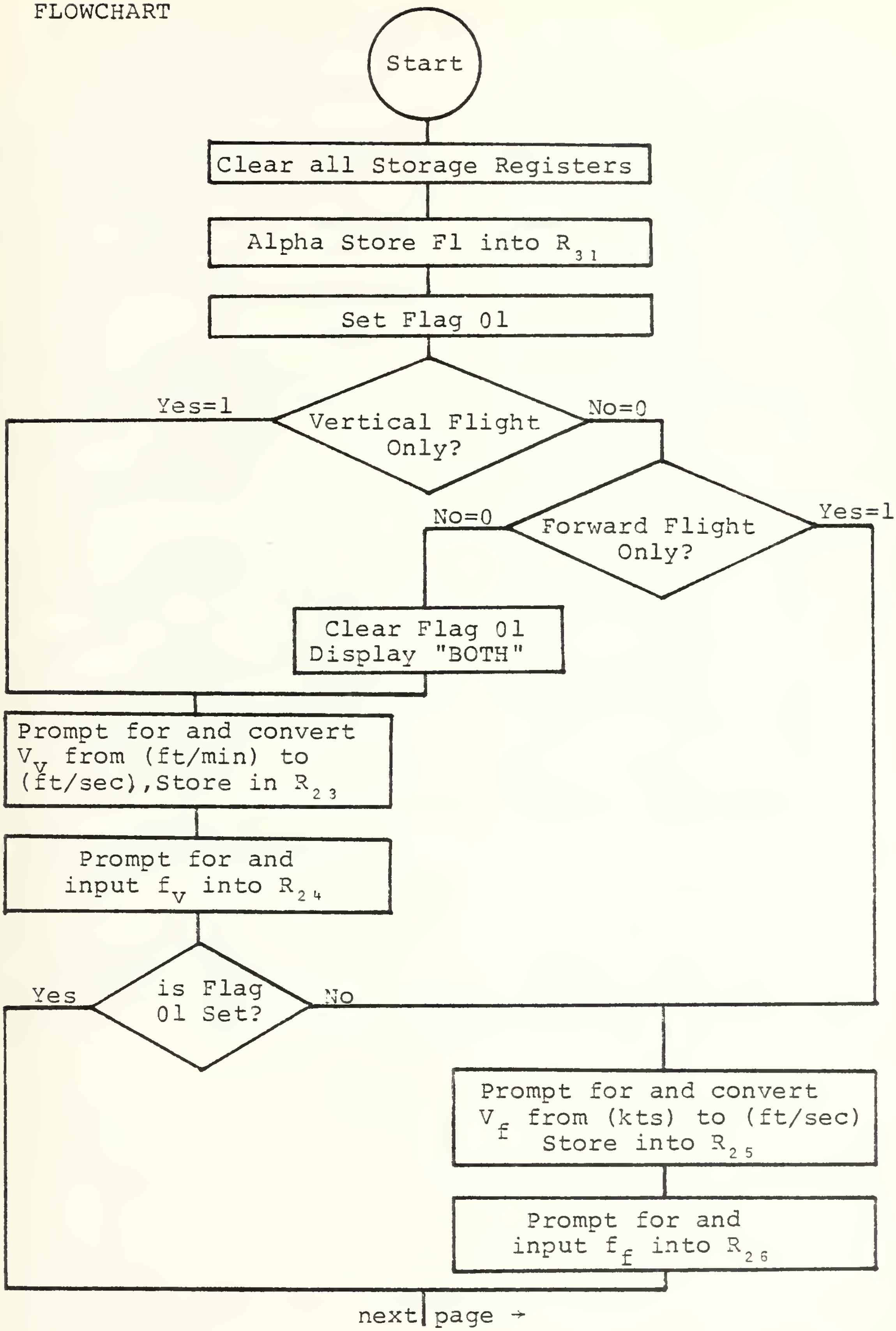
V_v is the vertical velocity (ft/sec)

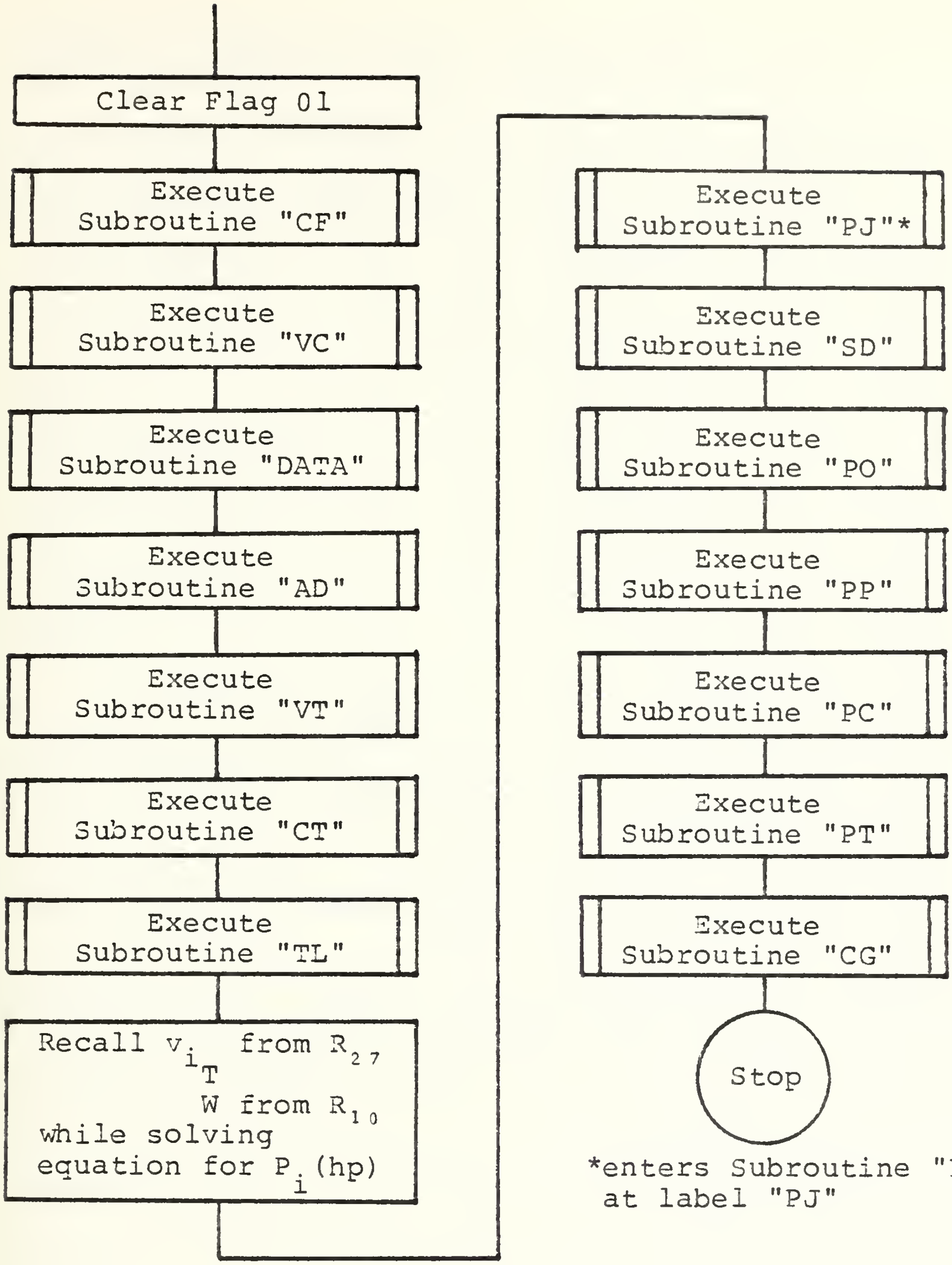
V_f is the forward velocity (ft/sec)

v_{i_T} is the vertical component of the induced velocity (ft/sec)

No other equations are found in the actual program itself. Consult the various subroutine listings for the equations used.

3. FLOWCHART


Start
Clear all Storage Registers
Alpha Store F1 into R_{31}
Set Flag 01
Vertical Flight Only?
Yes=1
No=0
Forward Flight Only?
No=0
Yes=1
Clear Flag 01
Display "BOTH"
Prompt for and convert V_v from (ft/min) to (ft/sec), Store in R_{23}
Prompt for and input f_v into R_{24}
is Flag 01 Set?
Yes
No
Prompt for and convert V_f from (kts) to (ft/sec) Store into R_{25}
Prompt for and input f_f into R_{26}
next page →



*enters Subroutine "PI" at label "PJ"

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the forward climbing flight power requirements for a UH-60A, Blackhawk, under the following conditions:

$C = 1.73$ ft	$\Omega = 258$ RPM $\rightarrow$ 27.02 rads/sec
$R = 26.835$ ft	$\bar{C}_{d_o} = .008$
$b = 4$	$V_v = 500$ ft/sec
$W = 18{,}250$ lbs	$f_v = 308$ ft^2
$h = 200$ ft	$V_f = 60$ kts
D.A. = 650 ft	$f_f = 25.69$ ft^2

Keystrokes:	Display:
[XEQ] [ALPHA] FLIGHT [ALPHA]	VERT ONLY?
(Execute Vertical Flight Only? 1 is Yes, 0 is No)	
0 [R/S]	FOR ONLY?
(Execute Forward Flight Only? 1 is Yes, 0 is No)	
0 [R/S]	BOTH
(The calculator is ready to do the combination of both, i.e. forward climbing flight)	
[R/S]	VERT V=?
500 [R/S]	F.P.A.(VF)=?
308 [R/S]	FOR V=?
60 [R/S]	F.P.A.(FF)=?
25.69 [R/S]	R=?
26.835 [R/S]	W=?
18,250 [R/S]	D.A.=?

650 [R/S]	REC?
(Rectangular Blade? 1 is Yes, 0 is No)	
1 [R/S]	C=?
1.73 [R/S]	R=?
26.835 [R/S]	b=?
4 [R/S]	CdO=?
.008 [R/S]	RV=?
27.02 [R/S]	H=?
200 [R/S]	W=?
18,250 [R/S]	D.A.=?
650 [R/S]	PI=
[R/S]	549.98
[R/S]	PI(TL)=
[R/S]	566.21
[R/S]	GE=0
[R/S]	PO=
[R/S]	325.07
[R/S]	PP=
[R/S]	57.05
[R/S]	PC=
[R/S]	276.52
[R/S]	PT(MR)=
[R/S]	1224.85
[R/S]	CHANGE?
0 [R/S]	0.00

Find the vertical flight power requirements for the same UH-60A under the same conditions with the only exception being that the forward flight velocity, V_f, is now equal to zero.

Keystrokes:	Display:
[R/S]	VERT ONLY?
1 [R/S]	VERT V=?
500 [R/S]	F.P.A.(VF)=?
308 [R/S]	R=?
26.835 [R/S]	W=?
18,250 [R/S]	D.A.=?
650 [R/S]	REC?
1 [R/S]	C=?
1.73 [R/S]	R=?
26.835 [R/S]	b=?
4 [R/S]	CdO=?
.008 [R/S]	RV=?
27.02 [R/S]	H=?
200 [R/S]	W=?
18,250 [R/S]	D.A.=?
650 [R/S]	PI=
[R/S]	1248.63
[R/S]	PI(TL)=
[R/S]	1285.50
[R/S]	GE=0
[R/S]	PO=

[R/S]	300.15
[R/S]	PP=
[R/S]	0.38
[R/S]	PC=
[R/S]	276.52
[R/S]	PT(MR)=
[R/S]	1,862.54
[R/S]	CHANGE?
0 [R/S]	0.00

note - When program "VERFLT" is executed for this case, the outputs are identical. Examination of subroutine "CF" and subroutine "VC" with $V_f = 0$, explains the reason for the identical results.

Find the forward (straight and level) flight power requirements for the same UH-60 under the original conditions with the only exception being that the vertical velocity, V_v, is now equal to zero.

Keystrokes:	Display:
[R/S]	VERT ONLY?
0 [R/S]	FOR ONLY?
1 [R/S]	FOR V=?
60 [R/S]	F.P.A.(FF)=?
25.69 [R/S]	R=?
26.835 [R/S]	W=?

18,250 [R/S]	D.A.=
650 [R/S]	PI=
[R/S]	558.69
[R/S]	PI(TL)=
[R/S]	575.18
[R/S]	GE=0
[R/S]	PO=
[R/S]	325.07
[R/S]	PP=
[R/S]	56.68
[R/S]	PT(MR)=
[R/S]	956.93
[R/S]	CHANGE?
0 [R/S]	0.00

note - When program "FORFLT" is executed for this case, the outputs are identical. Examination of subroutine "CF" and subroutine "VC" with $V_v = 0$, explains the reason for the identical results.

Find the hovering flight power requirements for the same UH-60 under the original conditions with the only exceptions being that both the vertical velocity, V_v, and the forward velocity, V_f, are equal to zero.

Keystrokes:	Display:
[R/S]	VERT ONLY?

0 [R/S]	FOR ONLY?
0 [R/S]	BOTH
[R/S]	VERT V=?
0 [R/S]	F.P.A.(VF)=?
308 [R/S]	FOR V=?
0 [R/S]	F.P.A.(FF)=?
25.69 [R/S]	R=?
26.835 [R/S]	W=?
18,250 [R/S]	D.A.=?
650 [R/S]	REC?
1 [R/S]	C=?
1.73 [R/S]	R=?
26.835 [R/S]	b=?
4 [R/S]	CdO=?
.008 [R/S]	RV=?
27.02 [R/S]	H=?
200 [R/S]	W=?
18,250 [R/S]	D.A.=?
650 [R/S]	PI=
[R/S]	1,379.98
[R/S]	PI(TL)=
[R/S]	1,420.73
[R/S]	GE=0
[R/S]	PO=
[R/S]	300.15
[R/S]	PP=

[R/S]	0.00
[R/S]	PT(MR)=
[R/S]	1,720.88
[R/S]	CHANGE?
0 [R/S]	0.00

note - When program "HOVER" is executed for this case, the outputs are identical. Examination of subroutine "CF" and subroutine "VC" with $V_f = 0$, and $V_v = 0$, explains the reason for the identical results.

The user of program "FLIGHT" might wonder at this time as to why it is even necessary to have programs "HOVER", "FORFLT", and "VERFLT" when it has now become obvious that program "FLIGHT" will do all three cases. Three reasons exist to substantiate the existence of these other three programs. First, program "FLIGHT" is a long program and, as such, requires 31 more program registers than any of the other three. Second, program "FLIGHT" has a longer running time than any of the other three. Subroutine "VC" alone will take an average of 30 seconds of execution time. And third, program "FLIGHT" involes some double prompting for the same input. The reasons for this were explained in subroutines "DATA and "CF". This procedure optimizes the use of data registers, but also increases the execution time.

Therefore, if the user's only desire is to execute pure hover, or forward flight, or vertical flight computations, then one of these other programs should be used. Both calculator memory space and calculator execution time will be significantly reduced.

5. PROGRAMS & SUBROUTINES USED

"AD"	"DN"	"PI" at label "PJ"	"TL"
"CF"	"ECHORD"	"PO"	"VC"
"CG"	"FLIGHT"	"PP"	"VI"
"CT"	"GE"	"PT"	"VT"
"DATA"	"PC"	"SD"	

6. PROGRAM LISTINGS

PROGRAM

```
 01♦LBL "FLI
GHT"
 02 CLRG
 03 "F1"
 04 ASTO 31
 05 SF 01
 06 "VERT ON
LY?"
 07 PROMPT
 08 X>0?
 09 GTO 04
 10 "FOR ONL
Y?"
 11 PROMPT
 12 X>0?
 13 GTO 05
 14 CF 01
 15 "BOTH"
 16 PROMPT
 17♦LBL 04
 18 "VERT V=
?"
 19 PROMPT
 20 60
 21 /
 22 STO 23
 23 "F.P.A.<
VF>=?"
 24 PROMPT
 25 STO 24
 26 FS? 01
 27 GTO 06
 28♦LBL 05
 29 "FOR V=?
"
 30 PROMPT
 31 1.68894
 32 *
 33 STO 25
 34 "F.P.A.<
FF>=?"
 35 PROMPT
 36 STO 26
 37♦LBL 06
 38 CF 01
 39 XEQ "CF"
 40 XEQ "VC"
 41 XEQ "DAT
```

```
A"
 42♦LBL "F1"
 43 XEQ "AD"
 44 XEQ "VT"
 45 XEQ "CT"
 46 XEQ "TL"
 47 RCL 27
 48 RCL 10
 49 *
 50 550
 51 /
 52 XEQ "PJ"
 53 XEQ "SD"
 54 XEQ "PO"
 55 XEQ "PP"
 56 XEQ "PC"
 57 XEQ "PT"
 58 XEQ "CG"
 59 END
```

TAILROTOR

1. PURPOSE

This main program computes the various tailrotor power requirements in terms of horsepower under all types of flight conditions. The tailrotor program must be executed immediately following the execution of any of the main rotor programs such as "HOVER", "FORFLT", "VERFLT", or "FLIGHT". The tailrotor program recalls and uses much of the information that the previously executed program has put into storage. By doing this, the tailrotor program is shortened. There is no need for regurgitation of input data and calculations for the main rotor, which is the starting point for all tailrotor computations. The various calculated power requirements are displayed as follows:

Display:	Explanation:
PI=	induced power for the tailrotor
PI(TL)=	induced power with tip losses for the tail-rotor
PO=	profile power for the tailrotor
PT(TR)=	total power for the tailrotor
PT(MR)=	total power for the main rotor
PT(ACFT)=	total power for the aircraft

2. EQUATIONS

$$P_{i_{(tr)}} = T_{(tr)} \cdot v_{i_{(tr)}} \tag{37}$$

$$T_{(tr)} = \frac{P_{(mr)}/\Omega_{(mr)}}{\ell_{tr}} \tag{38}$$

$$v_{i_{f(tr)}} = \left\{ -\frac{V_f^2}{2} + \left[\left(\frac{V_f^2}{2}\right)^2 + \frac{P_f^2}{\left(2A_{D_{(tr)}}\ell_{tr}\Omega_{(mr)}\rho\right)^2}\right]^{\frac{1}{2}} \right\}^{\frac{1}{2}} \tag{39}$$

$$v_{i_{(tr)}} = \frac{P_{h_{(mr)}}}{\left(2A_{D_{(tr)}}\ell_{tr}\Omega_{(mr)}\rho\right)} \tag{40}$$

$$P_{i_{f(tr)}} = T_{(tr)} \cdot v_{i_{f(tr)}} \tag{41}$$

$$P_{o_{f(tr)}} = \frac{1}{8}\sigma_{(tr)}\bar{C}_{d_{o(tr)}}\rho A_{D_{(tr)}} V_{T_{(tr)}}^3 \quad 1 + 4.3\left(\frac{V_f}{V_{T_{(mr)}}}\right)^2 \tag{42}$$

where:

$v_{i_{f(tr)}}$ is the induced velocity of the tailrotor in forward flight (ft/sec)

$P_{i_{f(tr)}}$ is the induced power required by tailrotor forward flight $\left[\frac{\text{ft-lb}_f}{\text{sec}}\right]$

$P_{o_{f(tr)}}$ is the profile power required by the tail-rotor in forward flight $\left[\frac{\text{ft-lb}_f}{\text{sec}}\right]$

$\bar{C}_{d_{o(tr)}}$ is the average profile drag coefficient of the tailrotor

$P_{h_{(mr)}}$ is the total power required by the main rotor in hover $\left[\frac{\text{ft-lb}_f}{\text{sec}}\right]$

$A_{D_{(tr)}}$ is the disc area of the tailrotor (ft^2)

$V_{T(tr)}$ is the tip velocity of the tailrotor (ft/sec)

$V_{T(mr)}$ is the tip velocity of the main rotor (ft/sec)

$v_{i(tr)}$ is the induced velocity of the tailrotor at a hover (ft/sec)

$P_{i(tr)}$ is the induced power required by the tailrotor at a hover $\left[\frac{ft\text{-}lb_f}{sec}\right]$

$T_{(tr)}$ is the required thrust for the tailrotor (lb_f)

$\Omega_{(mr)}$ is the rotational velocity of the main rotor system (radians/sec)

$\sigma_{(tr)}$ is the solidity of the tailrotor

$P_{(mr)}$ is the total power required by the main rotor $\left[\frac{ft\text{-}lb_f}{sec}\right]$

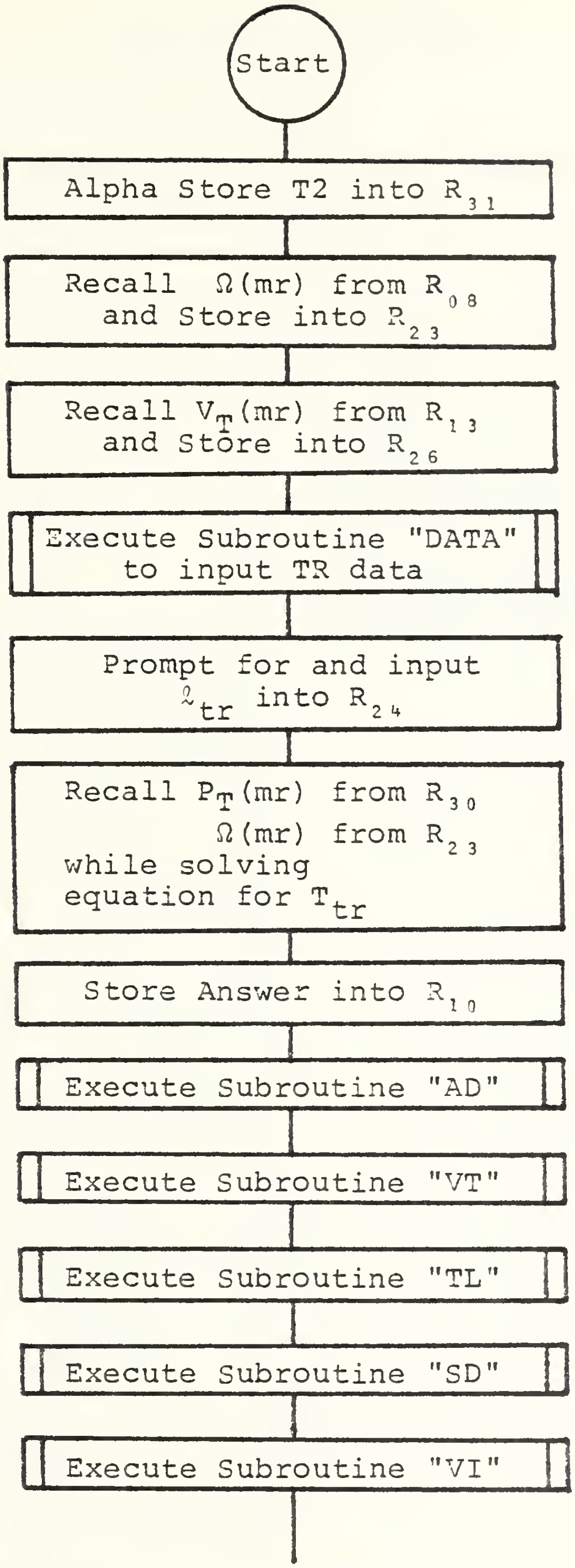
ℓ_{tr} is the tail length, the distance from the center of the main rotor system to the center of the tailrotor system (ft)

P_f is the total power required by the main rotor in forward flight $\left[\frac{ft\text{-}lb_f}{sec}\right]$

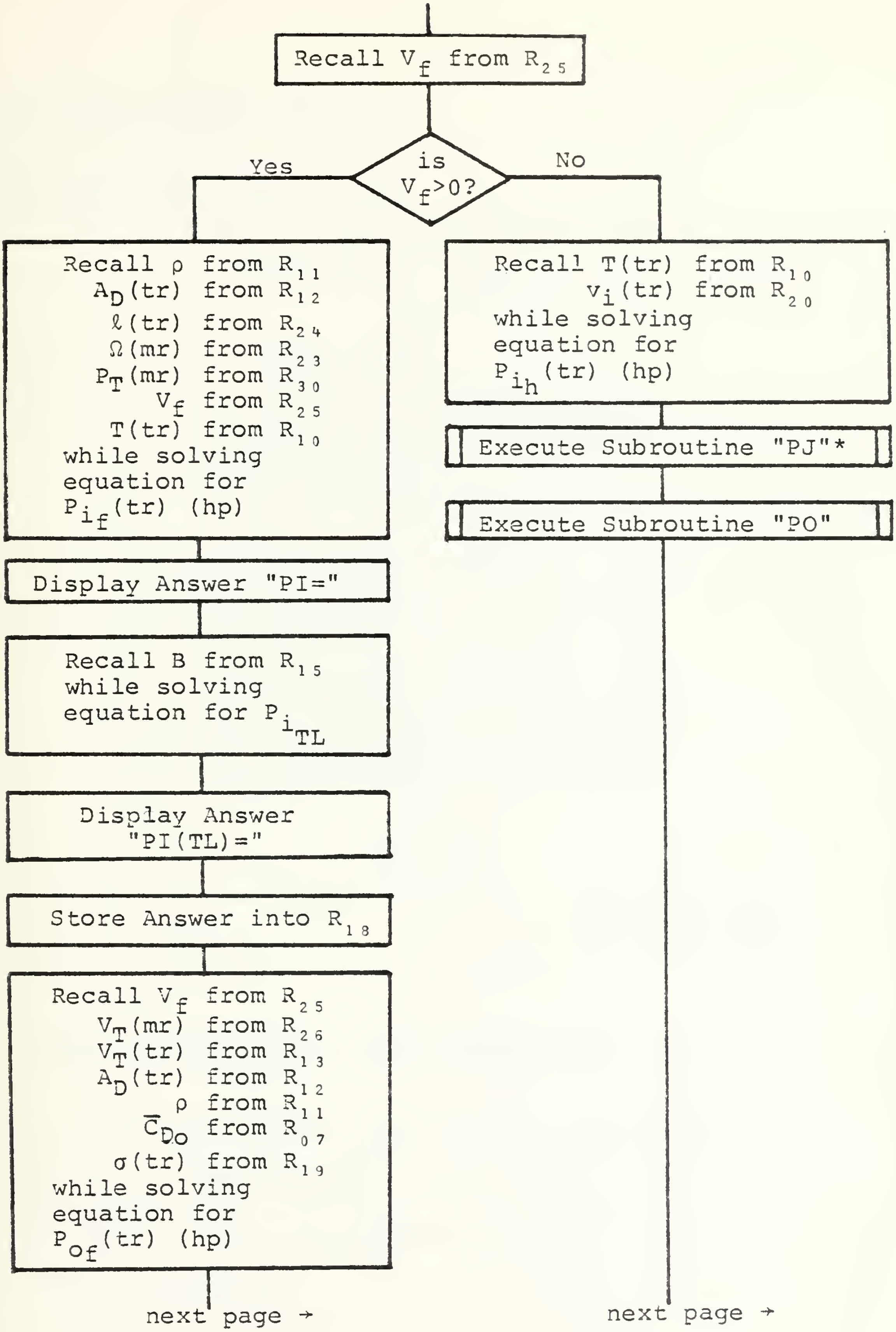
V_f is the forward velocity of the helicopter (ft/sec)

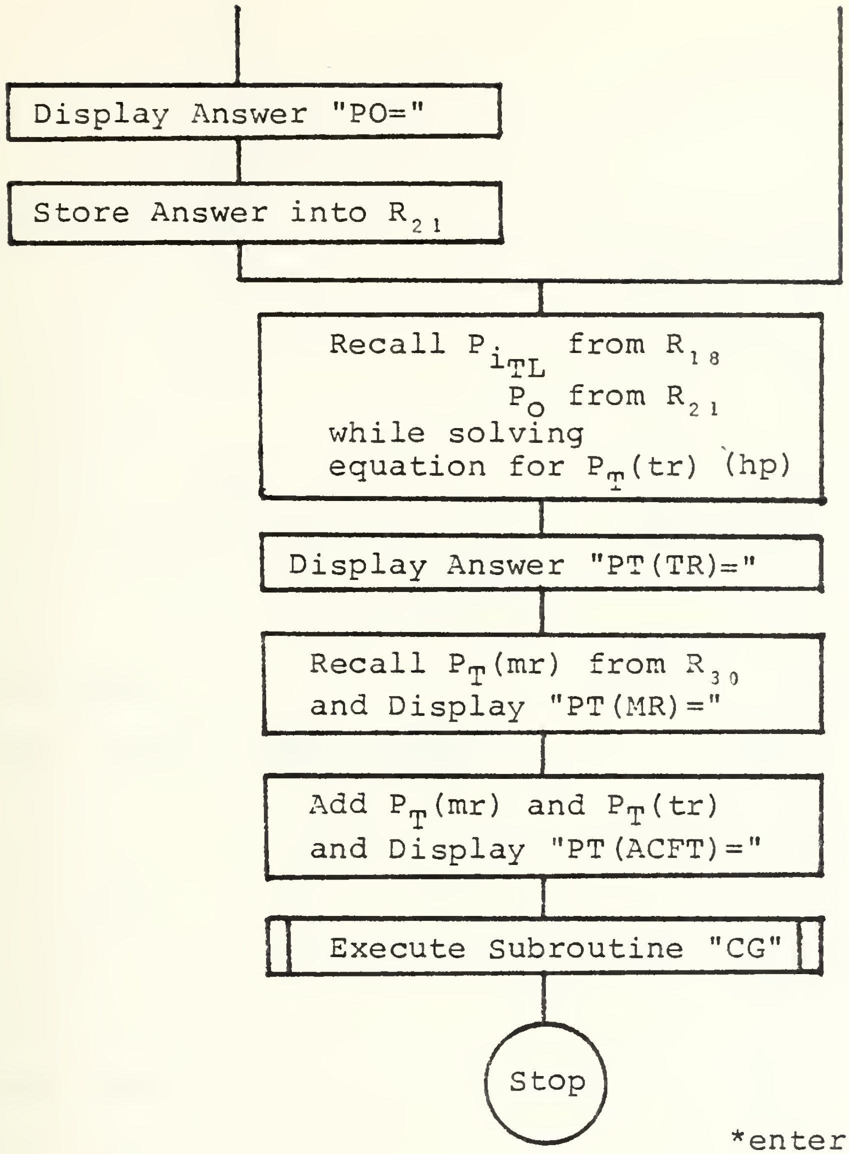
ρ is the density of the air $\left[\frac{lb\text{-}sec^2}{ft^4}\right]$

3. FLOWCHART



next page →


Recall V_f from R_{25}
is $V_f > 0$?
Yes
No
Recall ρ from R_{11}
A_D(tr) from R_{12}
ℓ(tr) from R_{24}
Ω(mr) from R_{23}
P_T(mr) from R_{30}
V_f from R_{25}
T(tr) from R_{10}
while solving equation for P_{i_f}(tr) (hp)
Display Answer "PI="
Recall B from R_{15} while solving equation for $P_{i_{TL}}$
Display Answer "PI(TL)="
Store Answer into R_{18}
Recall V_f from R_{25}
V_T(mr) from R_{26}
V_T(tr) from R_{13}
A_D(tr) from R_{12}
ρ from R_{11}
$\overline{C}_{Do}$ from R_{07}
σ(tr) from R_{19}
while solving equation for P_{of}(tr) (hp)
next page →
Recall T(tr) from R_{10}
v_i(tr) from R_{20}
while solving equation for P_{i_h}(tr) (hp)
Execute Subroutine "PJ"*
Execute Subroutine "PO"
next page →



*enters Subroutine "PI" at Label "PJ"

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the tailrotor power requirements for an SH-3H, Sea King, conducting a "LAMPS" mission while hovering above the surface of the ocean under the following flight conditions:

W = 18,650 lbs

$h = 54$ ft

D.A. = 0 ft

$\ell_{tr} = 36.6$ ft

Main Rotor Data:

$C = 1.52$ ft

$R = 31$ ft

$b = 5$

$\bar{C}_{d_o} = .0095$

$\Omega = 203$ RPM $\rightarrow 21.26 \ \frac{\text{rads}}{\text{sec}}$

Tail Rotor Data:

$C = 0.61$ ft

$R = 5.3$ ft

$b = 5$

$\bar{C}_{d_o} = .0105$

$\Omega = 1243$ RPM $\rightarrow 130.16 \ \frac{\text{rads}}{\text{sec}}$

Keystrokes:	Display:
[XEQ] [ALPHA] HOVER [ALPHA]	REC?
1 [R/S]	C=?
1.52 [R/S]	R=?
31 [R/S]	b=?
5 [R/S]	CdO=?
.0095 [R/S]	RV=?
21.26 [R/S]	H=?
54 [R/S]	W=?
18,650 [R/S]	D.A.=?
0 [R/S]	PI=
[R/S]	1222.36
[R/S]	PI(TL)=
[R/S]	1249.70
[R/S]	PI(TL+GE)=
[R/S]	1216.90

[R/S]	PO=
[R/S]	346.12
[R/S]	PT(MR)=
[R/S]	1563.02
[R/S]	CHANGE?
0 [R/S]	0.00
[XEQ] [ALPHA] TR [ALPHA]	TR DATA

Subroutine "DATA" is about to be executed. This prompt tells the user that the tail rotor data should now be entered.

[R/S]	REC?
1 [R/S]	C=?
.61 [R/S]	R=?
5.3 [R/S]	b=?
5 [R/S]	CdO=?
.0105 [R/S]	RV=?
130.16 [R/S]	H=?
54 [R/S]	W=?
18,650 [R/S]	D.A.=?
0 [R/S]	L(TAIL)=
36.6 [R/S]	PI=
[R/S]	103.08
[R/S]	PI(TL)=
[R/S]	106.25
[R/S]	GE=0
[R/S]	PO=

[R/S]	30.10
[R/S]	PT(TR)=
[R/S]	136.35
[R/S]	PT(MR)=
[R/S]	1563.02
[R/S]	PT(ACFT)=
[R/S]	1699.37
[R/S]	CHANGE?
1 [R/S]	C RV b R W

It is desired at this point to increase the length of the tail, ℓ_{tr}, from 36.6 to 41.6 feet. To observe what effect this change will have on the tailrotor power requirements flag 04 must be set to return to the main program where it then becomes possible to change ℓ_{tr}. The flowchart for subroutine "CG" depicts this process. In order to initiate this procedure, pick a variable and input its original value. In this example, b is used:

[$\sqrt{x}$]	b=?
5 [R/S]	CHANGE?
0 [R/S]	L(TAIL)=?
41.6 [R/S]	PI=
[R/S]	85.07
[R/S]	PI(TL)=
[R/S]	87.51
[R/S]	GE=0
[R/S]	PO=

[R/S]	30.10
[R/S]	PT(TR)=
[R/S]	117.61
[R/S]	PT(MR)=
[R/S]	1563.02
[R/S]	PT(ACFT]=
[R/S]	1680.63
[R/S]	CHANGE?
0 [R/S]	0.00

The same SH-3H is now returning to ship with V_f = 100 kts, h = 500ft, and f_f = 31.27 ft^2. Find the tailrotor power required.

Keystrokes:	Display:
[XEQ] [ALPHA] FORFLT [ALPHA]	FOR V=?
100 [R/S]	F.P.A.(FF)=?
31.27 [R/S]	REC?
1 [R/S]	C=?
1.52 [R/S]	R=?
31 [R/S]	b=?
5 [R/S]	CdO=?
.0095 [R/S]	RV=?
21.26 [R/S]	H=?
500 [R/S]	W=?
18,650 [R/S]	D.A.=?
0 [R/S]	PI=

[R/S]	260.63
[R/S]	PI(TL)=
[R/S]	266.46
[R/S]	GE=0
[R/S]	PO=
[R/S]	442.73
[R/S]	PP=
[R/S]	325.53
[R/S]	PT(MR)=
[R/S]	1034.71
[R/S]	CHANGE?
0 [R/S]	0.00
[XEQ] [ALPHA] TR [ALPHA]	TR DATA
[R/S]	REC?
1 [R/S]	C=?
.61 [R/S]	R=?
5.3 [R/S]	b=?
5 [R/S]	CdO=?
.0105 [R/S]	RV=?
130.16 [R/S]	H=?
500 [R/S]	W=?
18,650 [R/S]	D.A.=?
500 [R/S]	L(TAIL)=?
36.6 [R/S]	PI=
[R/S]	13.90
[R/S]	PI(TL)=

[R/S]	14.25
[R/S]	PO=
[R/S]	37.31
[R/S]	PT(TR)=
[R/S]	51.56
[R/S]	PT(MR)=
[R/S]	1034.71
[R/S]	PT(ACFT)=
[R/S]	1086.27
[R/S]	CHANGE?
0 [R/S]	0.00

note - the CHANGE? process can be executed as many times as the user may desire, but the whole of program "TR" can only be executed once. By examining the flowchart for this program, it can be seen that several main rotor data elements are moved about in the storage registers. This is done to conserve program memory. Therefore, it becomes necessary to go back and execute one of the other main rotor programs before again attempting to execute program "TR" in its entirity.

5. PROGRAMS & SUBROUTINES USED

"AD"	"ECHORD"	"TL"
"CG"	"GE"	"TR"
"CT"	"PI" at label "PJ"	"VI"
"DATA"	"PO"	"VT"
"DN"	"SD"	

6. PROGRAM LISTINGS

PROGRAM

```
01♦LBL "TR"
02 "T2"
03 ASTO 31
04 RCL 08
05 STO 23
06 RCL 13
07 STO 26
08 "TR DATA
"
09 PROMPT
10 XEQ "DAT
A"
11 1000
12 STO 09
13♦LBL "T2"
14 "L<TAIL>
=?"
15 PROMPT
16 STO 24
17 RCL 30
18 550
19 *
20 RCL 23
21 /
22 RCL 24
23 /
24 STO 10
25 XEQ "AD"
26 XEQ "VT"
27 XEQ "CT"
28 XEQ "TL"
29 XEQ "SD"
30 XEQ "VI"
31 RCL 25
32 X>0?
33 GTO 01
34 RCL 10
35 RCL 20
36 *
37 550
38 /
39 XEQ "PJ"
40 XEQ "PO"
41 GTO 02
42♦LBL 01
43 RCL 11
44 2
45 *
46 RCL 12
47 *
48 RCL 24
49 *
50 RCL 23
51 *
52 X↑2
53 1/X
54 RCL 30
55 550
56 *
57 X↑2
58 *
59 RCL 25
60 X↑2
61 2
62 /
63 STO 00
64 X↑2
65 +
66 SQRT
67 RCL 00
68 -
69 SQRT
70 RCL 10
71 *
72 550
73 /
74 "PI="
75 PROMPT
76 VIEW X
77 STOP
78 RCL 15
79 /
80 "PI<TL>=
"
81 PROMPT
82 VIEW X
83 STOP
84 STO 18
85 RCL 25
86 RCL 26
87 /
88 X↑2
89 RCL 26
90 X↑2
```

```
 91 *
 92 4.3
 93 *
 94 RCL 13
 95 X↑2
 96 /
 97 1
 98 +
 99 RCL 13
100 3
101 Y↑X
102 RCL 12
103 *
104 RCL 11
105 *
106 RCL 07
107 *
108 RCL 19
109 *
110 4400
111 /
112 *
113 "PO="
114 PROMPT
115 VIEW X
116 STOP
117 STO 21
118♦LBL 02
119 RCL 18
120 RCL 21
121 +
122 "PT<TR>=
"
123 PROMPT
124 VIEW X
125 STOP
126 RCL 30
127 "PT<MR>=
"
128 PROMPT
129 VIEW X
130 STOP
131 +
132 "PT<ACFT
>="
133 PROMPT
134 VIEW X
135 STOP
136 XEQ "CG"
137 END
```

AUTOROTATION

1. PURPOSE

This main program computes several values for a single rotor helicopter in vertical and forward flight autorotation. The computed values are displayed as follows:

Display:	Explanation:
VV=	vertical velocity in a vertical autorotation (ft/min)
VF(MIN.R.O.D.)=	forward autorotative flight velocity for minimum autorotative rate of descent (kts)
VV(MIN.R.O.D.)=	vertical autorotative velocity (ft/min) at the forward autorotative flight velocity for minimum autorotative rate of descent
d(HOR.GLIDE)=	horizontal distance travelled on the ground at the forward autorotative flight velocity for minimum rate of descent (ft)

2. EQUATIONS

$$\overline{C}_L = (3K_2/K_1)^{\frac{1}{2}} \tag{43}$$

$$\overline{C}_d = K_1\overline{C}_L{}^2 + K_2 \tag{44}$$

$$\overline{F} = \frac{(C_L{}^3/C_d{}^2)\cdot\sigma}{4} \tag{45}$$

$$V_v = \left[\frac{W}{2\cdot\rho\cdot A_D\cdot\overline{f}}\right]^{\frac{1}{2}} \tag{46}$$

$$\bar{f} = \frac{\bar{F}}{(1 + \bar{F})^2} \qquad (0<\bar{F}<1) \text{ Momentum Theory} \qquad (47)$$

$$\bar{f} = \frac{(2\bar{F} - \sqrt{3\bar{F}})}{(4\bar{F} - 3)} \qquad (\bar{F}>1) \text{ Glauert Equation} \qquad (48)$$

$$V_{f(\text{min ROD})} = 0.00867 \cdot R \cdot RPM \qquad (49)$$

$$V_{v(\text{min ROD})} = 0.251 \cdot R \cdot RPM \qquad (50)$$

$$d_{(\text{hor glide})} = \frac{h}{\tan\gamma} \qquad (51)$$

$$\gamma = \arcsin \frac{V_v}{V_f} \approx 16.6° \qquad (52)$$

where:

- $\bar{C}_L$ is the average coefficient of lift
- $\bar{C}_d$ is the average coefficient of drag
- K_1 is a real number coefficient called the lift coefficient multiplier in drag coefficient terms
- K_2 is a real number coefficient equal to C_{d_o}
- V_v is the vertical velocity in a vertical autorotation (ft/min)
- A_D is the area of the rotor disc (ft^2)
- σ is the solidity of the main rotor system
- ρ is the density of the air $\left[\frac{lb\text{-}sec^2}{ft^4}\right]$
- h is the height of the rotor system above the ground (ft)

$V_{f(min\ ROD)}$ is the forward autorotative flight velocity for minimum autorotative rate of descent (kts)

$V_{v(min\ ROD)}$ is the vertical autorotative velocity (ft/min) at the forward autorotative flight velocity for minimum autorotative rate of descent

$d_{(hor\ glide)}$ is the horizontal distance travelled on the ground (ft) at the forward autorotative flight velocity for minimum rate of descent

RPM is the rotational velocity of the main rotor system in revolutions/minute

$\bar{F}$ is a non-dimensional coefficient

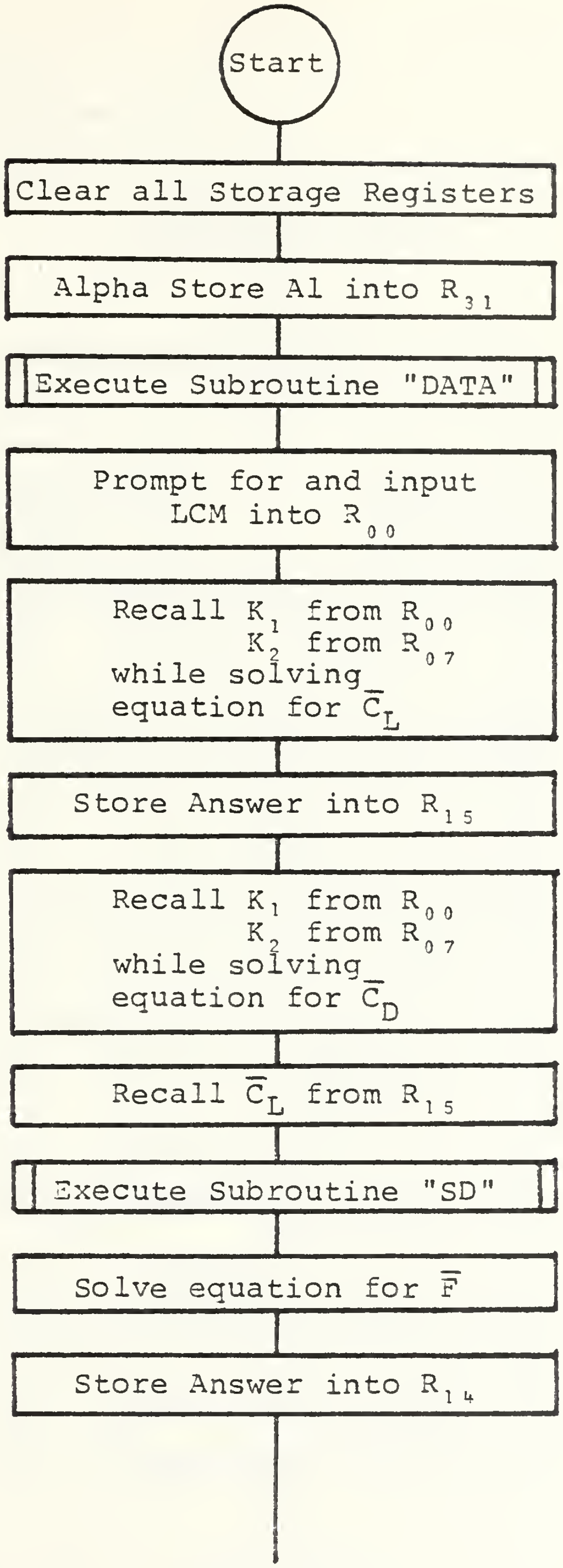
$\bar{f}$ is a non-dimensional coefficient

W is the weight of the helicopter (lbs)

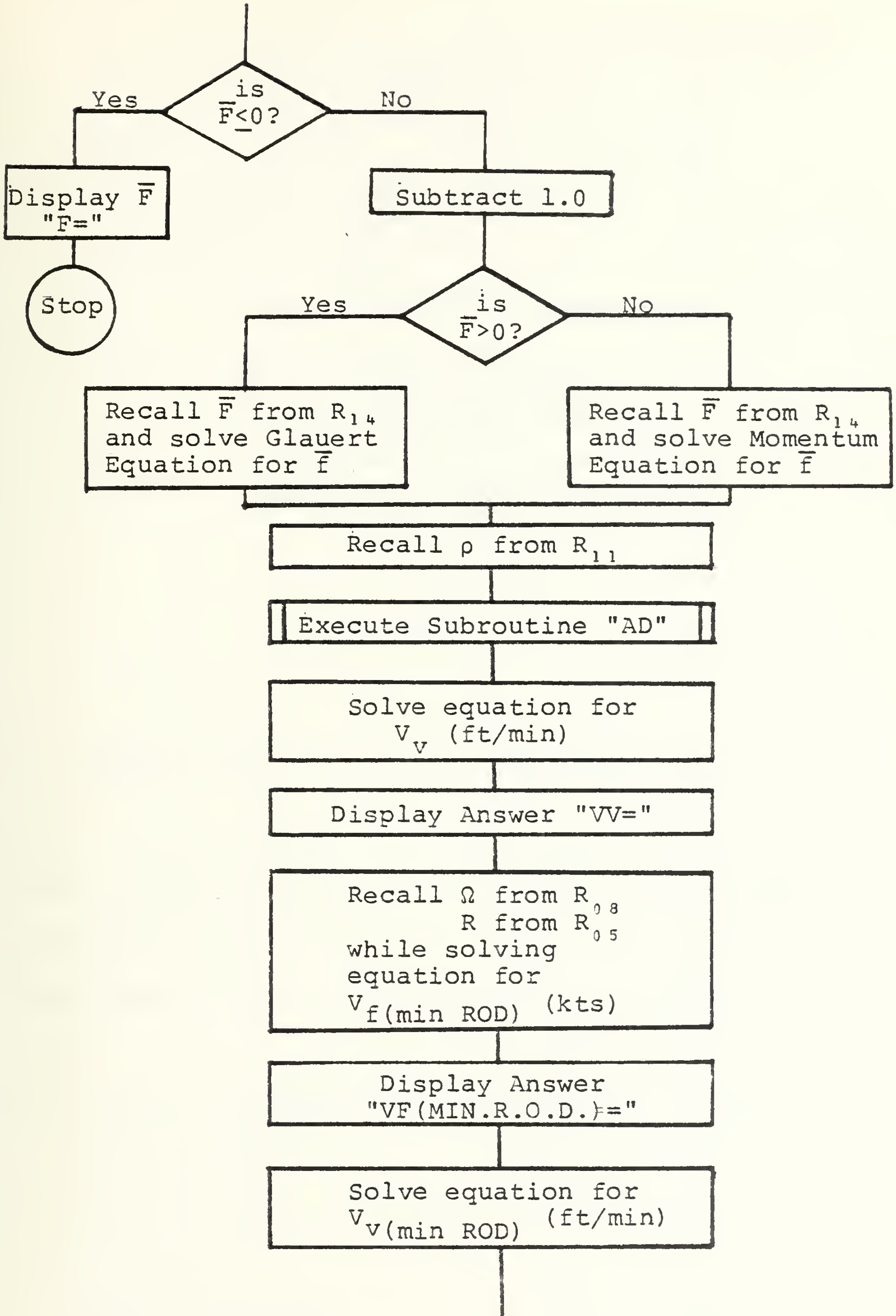
R is the radius of the rotor system (ft)

γ is the descent angle for minimum descent rate (degrees)

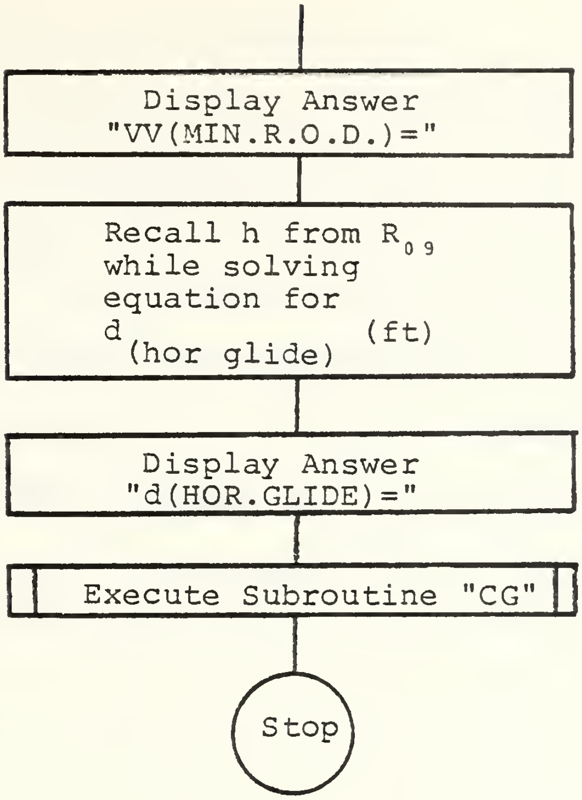
3. FLOW CHART



next page →


is F̄≤0?
Yes
No
Display F̄ "F="
Stop
Subtract 1.0
is F̄>0?
Yes
No
Recall F̄ from R14 and solve Glauert Equation for f̄
Recall F̄ from R14 and solve Momentum Equation for f̄
Recall ρ from R11
Execute Subroutine "AD"
Solve equation for Vv (ft/min)
Display Answer "VV="
Recall Ω from R08
R from R05
while solving equation for Vf(min ROD) (kts)
Display Answer "VF(MIN.R.O.D.)="
Solve equation for Vv(min ROD) (ft/min)

next page →



4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

note - if the display "F=" should appear, an error has been made in either the design or the input data itself. This will only occur when $\bar{F} \leq 0$. Neither this program nor the theory used will be able to calculate results for this situation.

For a UH-1H, Iroquois, with the following characteristics:

W = 8,200 lbs	NACA 0012 Main Rotor Blade:
h = 1,500 ft	R = 24 ft
b = 2	C = 1.75 ft
D.A. = 1,500 ft	$C_d = .0098 + .0120C_L^2$

Ω = 324 RPM → 33.927 radians/sec

find the rate of descent in a vertical autorotation, V_v; the forward flight autorotative velocity for minimum rate of descent, $V_{f(\text{min ROD})}$; the vertical velocity for the minimum rate of descent, $V_{v(\text{min ROD})}$; and the horizontal glide distance travelled during the autorotation, $d_{(\text{hor glide})}$.

Keystrokes:	Display:
[XEQ] [ALPHA] AUTO [ALPHA]	REC?
1 [R/S]	C=?
1.75 [R/S]	R=?
24 [R/S]	b=?
2 [R/S]	CdO=?
.0098 [R/S]	RV=?
33.927 [R/S]	H=?
1,500 [R/S]	W=?
8,200 [R/S]	D.A.=?
1,500 [R/S]	LCM=?
.012 [R/S]	VV=
[R/S]	2885.69
[R/S]	VF(MIN.R.O.D.)=
[R/S]	67.92
[R/S]	VV(MIN.R.O.D.)=
[R/S]	2043.85
[R/S]	d(HOR.GLIDE)=
[R/S]	5031.70
[R/S]	CHANGE?

It is now desired to increase the weight from 8,200 to 9,500 lbs:

1 [R/S]	C RV b R W
[LN]	W=?
9,500 [R/S]	CHANGE?
0 [R/S]	VV=?
[R/S]	3106.02
[R/S]	VF(MIN.R.O.D.)=
[R/S]	67.42
[R/S]	VV(MIN.R.O.D.)=
[R/S]	2043.85
[R/S]	d(HOR.GLIDE)=
[R/S]	5031.70
[R/S]	CHANGE?

It is now desired to decrease the rotor rotational velocity from 33.927 to 32.88 radians/second. This is 314 RPM.

1 [R/S]	C RV b R W
[1/x]	RV=?
32.88 [R/S]	CHANGE?
0 [R/S]	VV=
[R/S]	3106.02
[R/S]	VF(MIN.R.O.D.)=
[R/S]	65.34
[R/S]	VV(MIN.R.O.D.)=
[R/S]	1980.77
[R/S]	d(HOR.GLIDE)=

[R/S]	5031.70
[R/S]	CHANGE?
0 [R/S]	0.00

note - A reduced rate of descent during a forward flight autorotation can be achieved by attaining as low a rotor speed as possible without exceeding published limits (stall). Below a certain rotational velocity, rate of descent increases again, and the higher the weight, the higher the RPM at which this reversal occurs. [Ref. 6] Also, the forward speed for minimum descent rate is not the same forward speed for maximum glide distance. The forward speed for maximum glide distance will be higher than the forward speed for minimum descent rate. This "stretching the glide" not only results in a longer horizontal glide distance, but also results in an increased rate of descent. [Ref. 6]

5. PROGRAMS & SUBROUTINES USED

```
"AUTO"      "DN"
"AD"        "ECHORD"
"CG"        "SD"
"DATA"
```

6. PROGRAM LISTINGS

PROGRAM

```
01♦LBL "AUT
O"
02 CLRG
03 "A1"
04 ASTO 31
05 XEQ "DAT
A"
06 "LCM=?"
07 PROMPT
08 STO 00
09♦LBL "A1"
10 RCL 00
```

```
11 1/X
12 3
13 *
14 RCL 07
15 *
16 SQRT
17 STO 15
18 X↑2
19 RCL 00
20 *
21 RCL 07
22 +
23 X↑2
24 1/X
25 RCL 15
26 3
27 Y↑X
28 *
29 XEQ "SD"
30 *
31 4
32 /
33 STO 14
34 X<=0?
35 GTO 01
36 1
37 -
38 X>0?
39 GTO 02
40 2
41 +
42 X↑2
43 1/X
44 RCL 14
45 *
46 GTO 03
47◆LBL 02
48 RCL 14
49 3
50 *
51 SQRT
52 CHS
53 RCL 14
54 2
55 *
56 +
57 RCL 14
58 4
59 *
60 3
61 -
62 /
63◆LBL 03
64 RCL 11
65 *
66 XEQ "AD"
67 *
68 2
69 *
70 1/X
71 RCL 10
72 *
73 SQRT
74 60
75 *
76 "VV="
77 PROMPT
78 VIEW X
79 STOP
80 RCL 08
81 RCL 05
82 *
83 .0827985
84 *
85 "VF<MIN.
R.O.D.>="
86 PROMPT
87 VIEW X
88 STOP
89 30.3158
90 *
91 "VV<MIN.
R.O.D.>="
92 PROMPT
93 VIEW X
94 STOP
95 RCL 09
96 .29811
97 /
98 "d<HOR.G
LIDE>="
99 PROMPT
100 VIEW X
101 STOP
102 XEQ "CG"
103 GTO 04
104◆LBL 01
105 "F="
106 ARCL X
107 AVIEW
108◆LBL 04
109 END
```

TANDEM

1. PURPOSE

This main program computes the various power require- in terms of horsepower for a tandem rotor aircraft in either hovering flight or forward (straight and level) flight. The various calculated power requirements are displayed as follows:

Display:	Explanation:
PI(TL)=	induced power with tip losses
PI(TL+GE)=	induced power with tip losses plus ground effect
PO=	profile power for a single rotor system
PO(TDM)=	profile power for the tandem rotor system
PT(TDM)=	total power for the tandem rotor system

2. EQUATIONS

$$P_T = P_i + P_o + P_p \tag{20}$$

where:

P_T is the total power required

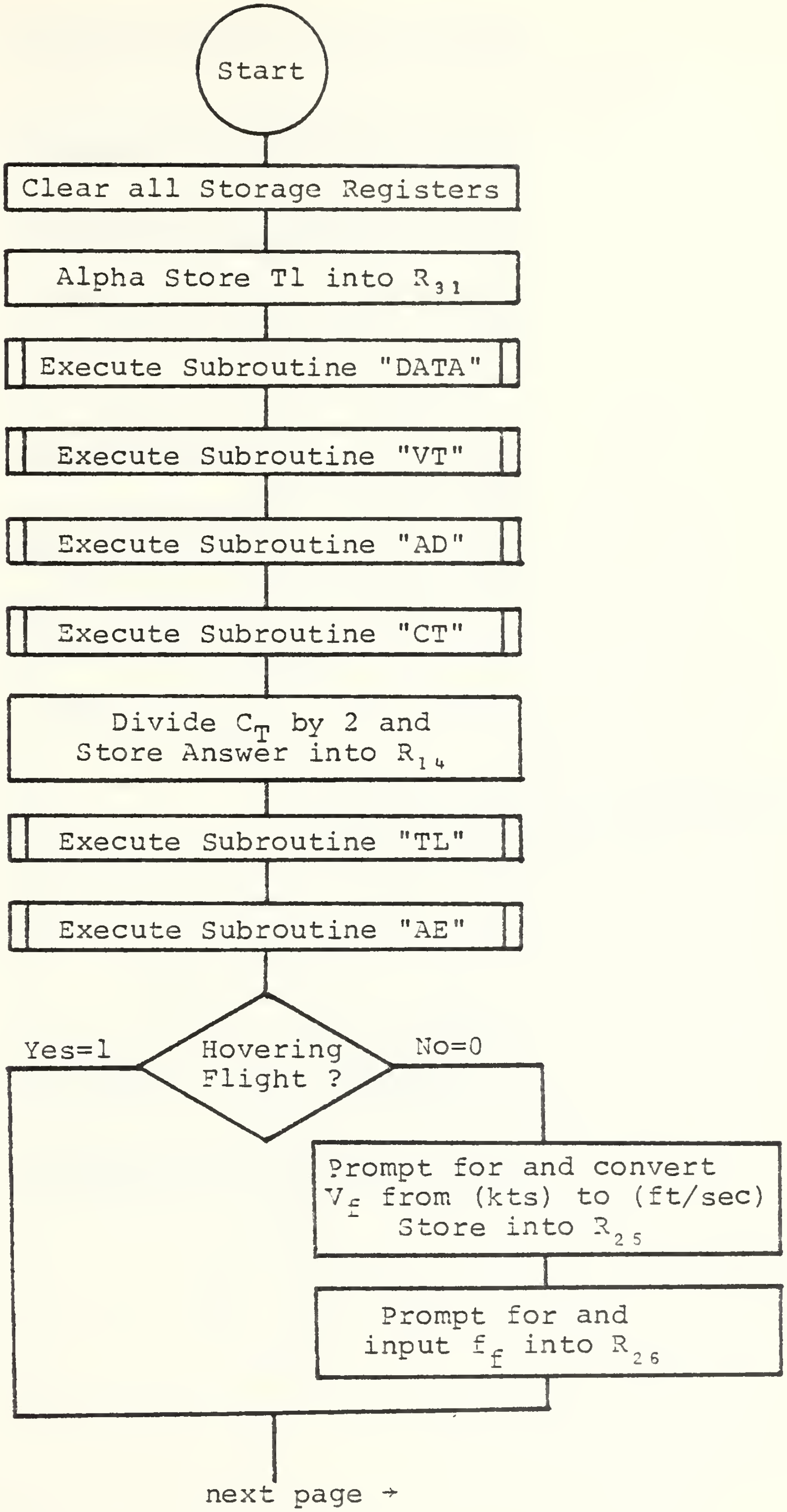
P_i is the induced power required

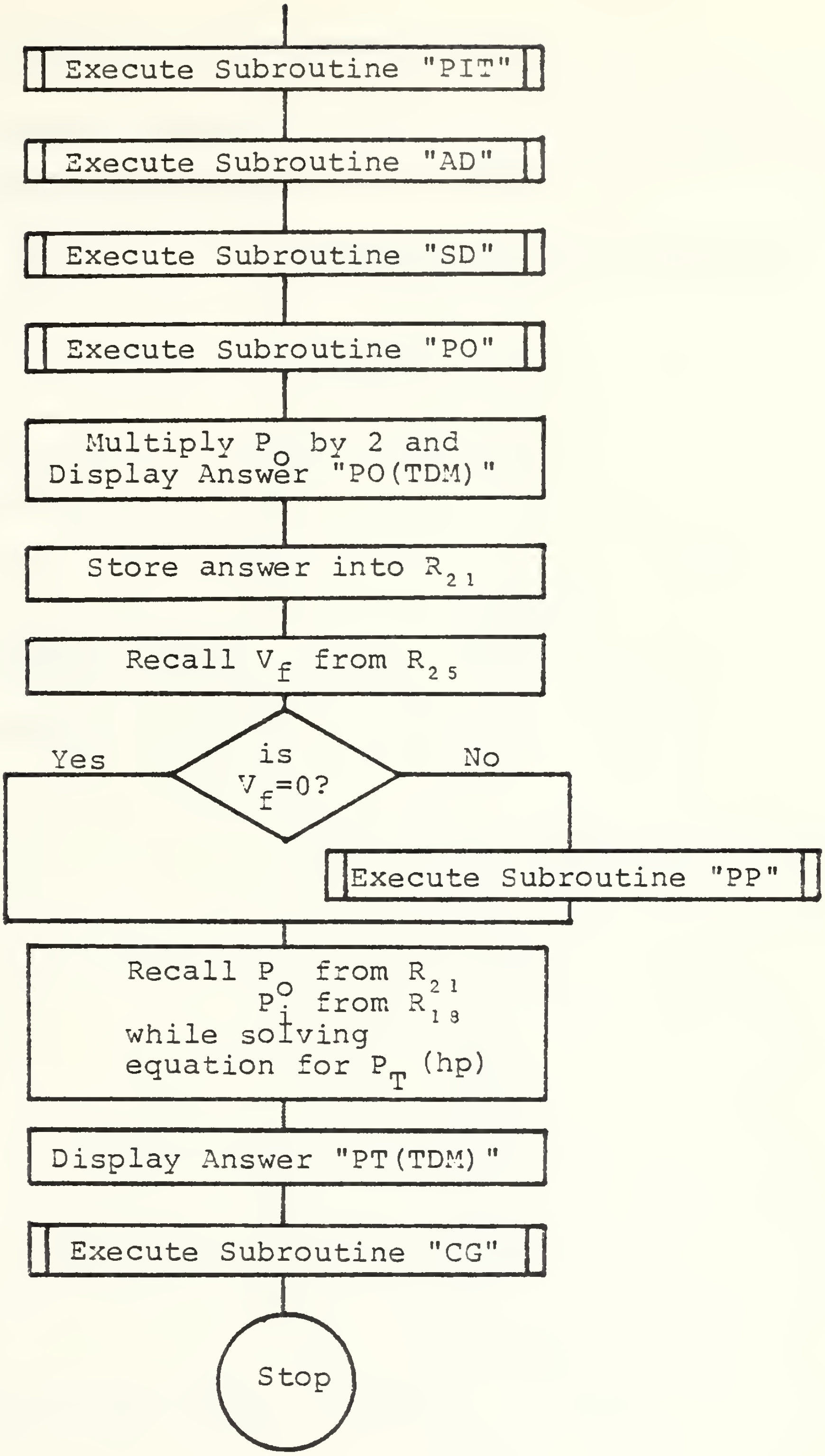
P_o is the profile power required

P_p is the parasite power required

No other equations are found in the program. Consult the subroutine listings for the various equations used.

3. FLOWCHART


Start
Clear all Storage Registers
Alpha Store Tl into R_{31}
Execute Subroutine "DATA"
Execute Subroutine "VT"
Execute Subroutine "AD"
Execute Subroutine "CT"
Divide C_T by 2 and Store Answer into R_{14}
Execute Subroutine "TL"
Execute Subroutine "AE"
Hovering Flight ?
Yes=1
No=0
Prompt for and convert V_f from (kts) to (ft/sec) Store into R_{25}
Prompt for and input f_f into R_{26}
next page →


Execute Subroutine "PIT"
Execute Subroutine "AD"
Execute Subroutine "SD"
Execute Subroutine "PO"
Multiply P_o by 2 and Display Answer "PO(TDM)"
Store answer into R_{21}
Recall V_f from R_{25}
is $V_f=0$?
Yes
No
Execute Subroutine "PP"
Recall P_o from R_{21} P_i from R_{18} while solving equation for P_T (hp)
Display Answer "PT(TDM)"
Execute Subroutine "CG"
Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Find the hover power requirements for a CH-47D, Chinook, under the following conditions:

C = 2.667 ft	Ω = 225 RPM → 23.56 rads/sec
R = 30.0 ft	$\bar{C}_{d_o}$ = .008
b = 3	h = 35 ft
W = 45,000 lbs	D.A. = 1,500 ft
d = 38.917 ft	

Keystrokes:	Display:
[XEQ] [ALPHA] TANDEM [ALPHA]	REC?
(Rectangular Blade? 1 is Yes, 0 is No)	
1 [R/S]	C=?
2.667 [R/S]	R=?
30 [R/S]	b=?
3 [R/S]	CdO=?
.008 [R/S]	RV=?
23.56 [R/S]	H=?
35 [R/S]	W=?
45,000 [R/S]	D.A.=?
1,500 [R/S]	d=?
38.917 [R/S]	HOVER?
(Execute Hovering Flight Only? 1 is Yes, 0 is No)	
1 [R/S]	PI(TL)=
[R/S]	4,263.48
[R/S]	PI(TL+GE)=

[R/S]	3,957.54
[R/S]	PO=
[R/S]	350.46
[R/S]	PO(TDM)=
[R/S]	700.93
[R/S]	PT(TDM)=
[R/S]	4,658.47
[R/S]	CHANGE?

(Change Data? 1 is Yes, 0 is No)

1 [R/S]	C RV b R W

It is desired at this point to increase the number of rotor blades per rotor system from 3 to 4. To observe what effect this change will have on the hover power requirements, press the key on the calculator keyboard directly beneath the variable in need of change. In this case the [$\sqrt{x}$] key is directly beneath the b in the display:

[$\sqrt{x}$]	b=?
4 [R/S]	CHANGE?

(Any Further Changes? 1 is Yes, 0 is No)

0 [R/S]	d=?

The calculator has returned to the top of the main program and now presents the opportunity to change the distance between the rotor shafts, d. In this example, d remains the same:

38.917 [R/S]	HOVER?

1 [R/S]	PI(TL)=
[R/S]	4,227.80
[R/S]	PI(TL+GE)=
[R/S]	3,924.43
[R/S]	PO=
[R/S]	467.28
[R/S]	PO(TDM)=
[R/S]	934.57
[R/S]	PT(TDM)=
[R/S]	4,859.00
[R/S]	CHANGE?
0 [R/S]	0.00

Find the forward flight (straight and level) power requirements for a CH-46E, Sea Knight, under the following flight conditions:

$C = 1.5625$ ft	$\Omega = 264$ RPM $\rightarrow$ 27.64 rads/sec
$R = 25.5$ ft	$\overline{C}_{d_o} = .009$
$b = 3$	D.A. = 2,000 ft
$W = 22{,}000$ lbs	$V_f = 100$ kts
$d = 33.33$ ft	$f_f = 44.3$ ft^2
$h = 2{,}000$ ft	

Keystrokes:	Display:
[R/S]	REC?
1 [R/S]	C=?
1.5625 [R/S]	R=?

25.5 [R/S]	b=?
3 [R/S]	CdO=?
.009 [R/S]	RV=?
27.64 [R/S]	H=?
2,000 [R/S]	W=?
22,000 [R/S]	D.A.=?
2,000 [R/S]	d=?
33.33 [R/S]	HOVER?
0 [R/S]	FOR V=?
100 [R/S]	F.P.A.(FF)=?
44.3 [R/S]	PI(TL)=
[R/S]	3,235.14
[R/S]	GE=0
[R/S]	PO=
[R/S]	238.65
[R/S]	PO(TDM)=
[R/S]	477.30
[R/S]	PP=
[R/S]	434.78
[R/S]	PT(TDM)=
[R/S]	4,147.22
[R/S]	CHANGE?
1 [R/S]	C RV b R W

It is desired at this point to decrease the forward flight velocity, V_f, from 100 to 50 knots. To observe what effect

this change will have on the forward flight power requirements flag 04 must be set to return to the main program where it then becomes possible to change V_f. The flowchart for subroutine "CG" depicts this process. In order to initiate this procedure, pick a variable and input its original value. In this example, W is used:

[LN]	W=?
22,000 [R/S]	CHANGE?
0 [R/S]	d=?
33.33 [R/S]	HOVER?
0 [R/S]	FOR V=?
50 [R/S]	F.P.A.(FF)=?
44.3 [R/S]	PI(TL)=
[R/S]	3,085.23
[R/S]	GE=0
[R/S]	PO=
[R/S]	203.54
[R/S]	PO(TDM)=
[R/S]	407.08
[R/S]	PP=
[R/S]	54.35
[R/S]	PT(TDM)=
[R/S]	3,546.66
[R/S]	CHANGE?
0 [R/S]	0.00

5. PROGRAMS & SUBROUTINES USED

"AD"	"ECHORD"	"SD"
"AE"	"GE"	"TANDEM"
"CG"	"PI" at label "TJ"	"TL"
"CT"	"PIT"	"VT"
"DATA"	"PO"	
"DN"	"PP"	

6. PROGRAM LISTINGS

PROGRAM

```
 01♦LBL "TAN
DEM"
 02 CLRG
 03 "T1"
 04 ASTO 31
 05 XEQ "DAT
A"
 06♦LBL "T1"
 07 XEQ "VT"
 08 XEQ "AD"
 09 XEQ "CT"
 10 2
 11 /
 12 STO 14
 13 XEQ "TL"
 14 XEQ "AE"
 15 "HOVER?"
 16 PROMPT
 17 X>0?
 18 GTO 02
 19 "FOR V=?
"
 20 PROMPT
 21 1.68894
 22 *
 23 STO 25
 24 "F.P.A.<
FF>=?"
 25 PROMPT
 26 STO 26
 27♦LBL 02
 28 XEQ "PIT
"
 29 XEQ "AD"
 30 XEQ "SD"
 31 XEQ "PO"
 32 2
 33 *
 34 "PO<TDM>
="
 35 PROMPT
 36 VIEW X
 37 STOP
 38 STO 21
 39 RCL 25
 40 X=0?
 41 GTO 03
 42 XEQ "PP"
 43♦LBL 03
 44 RCL 21
 45 +
 46 RCL 18
 47 +
 48 "PT<TDM>
="
 49 PROMPT
 50 VIEW X
 51 STOP
 52 XEQ "CG"
 53 END
```

CHECKS

1. PURPOSE

This program performs a short series of checks on several important parameters. It is executed immediately following the execution of one of the main programs. This program recalls and uses data that the previously executed program has put into storage. The various parameters that are checked are displayed as follows:

Display:	Explanation:
SOLID=	the solidity of the rotor system
U=	the advance ratio
M(TIP)=	the Mach Number at the tip of the advancing rotor blade
D.L.=	the disc loading of the rotor system

2. EQUATIONS

$$a = \sqrt{\gamma \cdot g_c \cdot R \cdot T(°R)} \tag{53}$$

$$T(°K) = T(°C) + 273.16 \tag{54}$$

$$T(°R) = T(°K) \div 0.5555 \tag{55}$$

$$M_T = \frac{V_f + V_T}{a} \tag{56}$$

$$\mu = \frac{V_f}{V_T} \tag{57}$$

$$\text{DISC LOADING} = \frac{W}{A_D} \tag{58}$$

where:

$T(°C)$ is the temperature in degrees centigrade

$T(°K)$ is the temperature in degrees kelvin

$T(°R)$ is the temperature in degrees rankine

g_c is the gravitational constant $\left[32.174 \ \frac{lb_m\text{-}ft}{lb_f\text{-}sec^2}\right]$

A_D is the rotor disc area (ft^2)

M_T is the Mach Number at the tip of the advancing rotor blade

V_f is the forward velocity of the helicopter (ft/sec)

V_T is the tip speed of the rotor blade (ft/sec)

R is the gas constant for air $\left[53.3 \ \frac{ft\text{-}lb_f}{lb_m\text{-}°R}\right]$

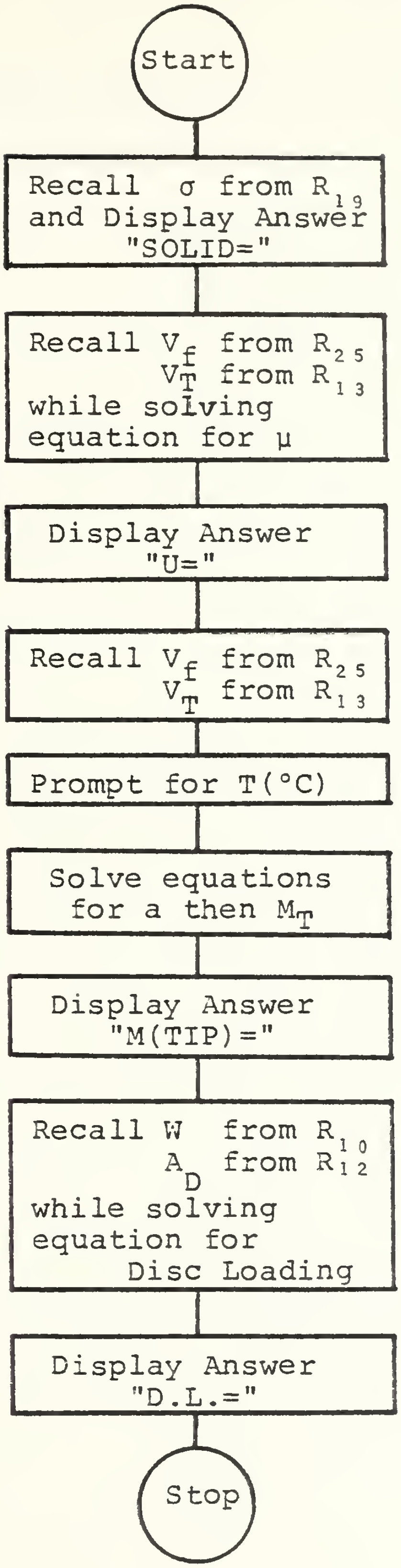
W is the weight (lbs)

μ is the advance ratio

a is the sonic velocity (ft/sec)

γ is the ratio of specific heats (1.4 for air)

3. FLOWCHART



Start
Recall σ from R19 and Display Answer "SOLID="
Recall Vf from R25 VT from R13 while solving equation for μ
Display Answer "U="
Recall Vf from R25 VT from R13
Prompt for T(°C)
Solve equations for a then MT
Display Answer "M(TIP)="
Recall W from R10 AD from R12 while solving equation for Disc Loading
Display Answer "D.L.="
Stop

4. EXAMPLE PROBLEMS AND USER INSTRUCTIONS

Execute program "FORFLT" for the CH-53E under the following characteristics and flight conditions:

$C = 2.44$ ft	$\Omega = 179$ RPM $\rightarrow$ 18.743 rads/sec
$R = 39.5$ ft	$V_f = 140$ kts
$b = 7$	$f_f = 63.57$ ft^2
$h = 1000$ ft	$\bar{C}_{d_o} = .009$
$W = 70{,}000$ lbs	D.A. = 1000 ft

Keystrokes:	Display:
[XEQ] [ALPHA] FORFLT [ALPHA]	FOR V=?
140 [R/S]	F.P.A.(FF)=?
63.57 [R/S]	REC?
1 [R/S]	C=?
2.44 [R/S]	R=?
39.5 [R/S]	b=?
7 [R/S]	CdO=?
.009 [R/S]	RV=?
18.743 [R/S]	H=?
1000 [R/S]	W=?
70,000 [R/S]	D.A.=?
1000 [R/S]	PI=
[R/S]	1662.62
[R/S]	PI(TL)=
[R/S]	1699.10
[R/S]	GE=0

[R/S]	PO=
[R/S]	1852.87
[R/S]	PP=
[R/S]	1763.38
[R/S]	PT(MR)=
[R/S]	5315.35
[R/S]	CHANGE?
0 [R/S]	0.00

Now, execute program "CHECKS" in order to make a quick check on σ, μ, M_T, and Disc Loading. The temperature is 13° C

Keystrokes:	Display:
[XEQ] [ALPHA] CHECKS [ALPHA]	SOLID=0.1376
[R/S]	U=0.3194
[R/S]	T=?
13 [R/S]	M(TIP)=0.8783
[R/S]	D.L.=14.2808

It is important to note here that the blade loading is above 10 lbs/ft^2. This generates high induced velocities, which in turn can make operations in unimproved sites hazardous due to flying debris. Also, it becomes increasingly difficult to obtain safe autorotational characteristics at these higher disc loadings. [Ref. 7]

The tip Mach Number is above 0.85. This means that the advancing rotor blade is entering the transonic flow region and shock wave formation will lead to wave drag.

Blade stall effects on the retreating rotor blade have started prior to this. Therefore the actual horsepower required in forward flight will be somewhat higher due to the effects of compressibility and blade stall. [Ref. 3]

5. PROGRAMS & SUBROUTINES USED

"CHECKS"

6. PROGRAM LISTINGS

PROGRAM

```
 01♦LBL "CHE
CKS"
 02 FIX 4
 03 RCL 19
 04 "SOLID="
 05 ARCL X
 06 AVIEW
 07 STOP
 08 RCL 25
 09 RCL 13
 10 /
 11 "U="
 12 ARCL X
 13 AVIEW
 14 STOP
 15 RCL 25
 16 RCL 13
 17 +
 18 "T=?"
 19 PROMPT
 20 273.16
 21 +
 22 .5555
 23 /
 24 2400.824
 25 *
 26 SQRT
 27 /
 28 "M<TIP>=
"
 29 ARCL X
 30 AVIEW
 31 STOP
 32 RCL 10
 33 RCL 12
 34 /
 35 "D.L.="
 36 ARCL X
 37 AVIEW
 38 END
```

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6. Saunders, George H., Dynamics of Helicopter Flight, John Wiley & Sons, Inc., 1975.

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